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TITLE- An Analysis of Work/Rest Cycles and
Crew Performance for Various Lunar
Environs Timeline Configurations

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ABSTRACT

A generalized model for the construction and analysis of lunar mission timelines is developed and demonstrated. Four specific tools form the basis of the technique. A trajectory constraint diagram aids in scheduling trajectory-restricted events. Work/rest alternatives are identified and displayed in a decision matrix. The alternatives are compared and contrasted in a time matrix. The advantage of a particular timeline in terms of performance during critical activities is measured by a performance rating system.

The technique deals with the broad aspects of work/rest cycling and crew performance in the overall timeline, rather than the detailed procedures employed in specific activities. For the first lunar landing mission, four prime timelines, each approximating a nominal 16/8 work/rest cycle, are developed. For each prime timeline a set of real time alternate timelines is developed, reflecting crew decisions not to sleep at the prescribed time. Evaluation of the timelines and real time alternates considers real time flexibility, probable performance levels during critical activities, time in lunar orbit, and time on the lunar surface as primary parameters.

It is concluded that split LM activation and checkout permits sleep on the lunar surface after EVA, and that this option provides maximum real time flexibility and the best probability of high crew performance during landing and docking. This timeline configuration also reduces time in lunar orbit over a single LM activation and checkout period with sleep before EVA. Further reductions in lunar orbit time, and thus mission time, are obtained by performing a portion of LM activation and check-prior to lunar orbit insertion, and even greater savings by elimination of the second insertion burn.

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FROM: P. Benjamin

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TECHNICAL MEMORANDUM

1.0 INTRODUCTION

As has been demonstrated in the Apollo 8 mission, the provision of adequate opportunity to rest in an operational timeline can be critical to mission success. An attempt is made here, therefore, to examine some of the work/rest timeline configurations in the lunar environs possible within the general mission constraints. Specific application of the general techniques developed is made to the first lunar landing (G1) mission.

Section 6 draws some conclusions from the analysis described below. Basic constraints, primarily sequence and trajectory oriented, as discussed in section 2, provide the structure for timeline development. A trajectory constraint diagram is developed to aid in the scheduling of trajectory-restricted events. Associated with each event or activity is a block of time to encompass the operations to be performed. These basic building blocks of the timeline are discussed in detail in section 3. Emphasis is placed upon the relationship of the blocks to the overall timeline and resulting work/rest cycles, rather than upon the detailed procedures employed within each block. Construction of possible timelines and various work/rest configurations involves the manipulation of these time blocks. The possible work/rest choices available within the constraints are isolated and displayed in a decision matrix. The resulting timelines shown in the appendix are discussed in section 4. A time matrix is used in section 5 as a framework for comparisons and tradeoffs between the various timelines developed. A performance rating scheme is also developed in an attempt to measure the overall crew performance level during critical activities that can be expected in a particular work/rest configuration.

It is assumed that an ideal work period of 16 hours and rest period of 8 hours would comprise a nominal day, and the four prime timelines A, B, C, and D presented approximate this work/rest cycle. It is recognized, however, that real time variations in planned timelines almost inevitably occur. Accordingly the proposed timelines include sufficient inherent

slack to accomodate many of these changes. Real time decisions not to sleep during the prescribed periods result in alternate timelines with more significant variations in the planned work/rest cycle. These changes are reflected in a set of real time alternate timelines associated with each prime timeline. A real time alternate is identified by the nominal timeline letter designation followed by a number which indicates the number of decisions made to defer sleep from the scheduled times. Thus real time alternate B1 reflects the result of a single decision not to sleep at a prescribed point in prime timeline B. Similarly B2 indicates a double no-sleep decision in timeline B. Each prime timeline and its associated real time alternates form a family which represent a planned timeline and the results of real time decisions to deviate from that plan. Tables 1 and 3, discussed in detail in sections 4.0 and 6.0, summarize the timeline families developed. The effects of slippage from planned to real time alternate timelines are considered in the analysis of the benefits of specific timeline configurations.

Awake time (the number of hours since the last sleep) is used in this analysis as a rough indicator of crew performance level. An implicit assumption of the analysis is that over long periods of time (i.e. more than 2 or 3 hours) average work loads are approximately the same. It is acknowledged that specific activities may require greater effort for short periods of time, but these are assumed to average out over the long run. In this manner probable levels of performance are determined for specific timelines and the various timelines can be compared.

The question of simultaneous or sequential sleep is not directly addressed. During the lunar phase of the mission, however, simultaneous sleep would appear to provide some advantages. Certainly the two men on the lunar surface must sleep simultaneously (if they are to sleep at all) in order to stay within hardware and timeline constraints, not to mention efficiency aspects. Since the remaining man in lunar orbit cannot affect LM systems, nor can CSM systems be affected by the surface crew, scheduling all three to sleep simultaneously does not reduce system safety. If the Mission Control Center is to be relied upon to monitor CSM systems while the CMP is orbiting alone (acknowledging a 75 minute monitored/45 minute unmonitored cycle) similar support could be expected when and if all three crew members sleep simultaneously in orbit. Of course, if such monitoring is acceptable in the lunar orbit phase, simultaneous sleep with full time ground support during coast phases should prove reasonable. The timelines presented here follow the CDR and LMP to the lunar surface, and do not consider separate CMP activities in orbit.

It is also assumed that the work/rest cycle prior to the lunar orbit phase is adjusted to allow appropriate transition to the planned timeline in lunar orbit. A similar assumption is made for trans earth coast (TEC), and neither coast phase is dealt with explicitly in this discussion.

2.0 CONSTRAINTS

The four discrete events shown in Figure 1, lunar orbit insertion (LOI), touchdown (TD), lift-off (LO), and trans earth injection (TEI), define the three basic phases of lunar environs operations. Although the time between these events may vary, they must occur in the order indicated, and thereby they define the sequence of activities. That is, lunar surface EVA cannot precede TD, nor can descent precede LOI.

Each of these events is trajectory constrained, and may only occur at one specific point in every revolution. LOI and TEI are constrained by the relationship between the lunar orbit and the position of the earth, and TD and LO are constrained by the relationship between the lunar orbit and the specific lunar landing site.

A 60 nm, two hour lunar orbit implies a 3° per minute rate of revolution. It also means that the orbiting vehicle passes over the same spot on the lunar surface at the same time in its two hour cycle for every revolution. Specifically, there is a one to one relationship between elapsed time per revolution and location over the lunar surface.

Such an analogy assumes a perfect 120 min. orbit and no lunar rotation or a 120.3 min. orbit with lunar rotation. For working purposes, and for the relatively short lunar stays contemplated, however, even the projected 119 min. orbit and 0.5° per hour lunar rotation produce errors well within the tolerance of broad work/rest timeline planning. The granularity used in this analysis is on the order of 15 minutes for the scheduling of events (e.g., TEI). However, the slack inherent in the activity allocations allows for the precise scheduling of trajectory constrained events when required.

Given the assumptions stated, it is possible, as shown in Figure 2, to relate fixed events to specific times in the revolution and specific points over the lunar surface. In this figure, and in the work presented here, TD is taken to be time zero. All events preceding TD are at negative times, and all events following TD are at positive times. Rotating counterclockwise in Figure 2 gives negative times preceding TD, and clockwise rotation gives positive times

following TD. Thus the left half of the diagram corresponds to even-numbered negative hours and odd-numbered positive hours. The right half of the diagram corresponds to even-numbered positive hours and odd-numbered negative hours.

For example, the figure shows that LOI must occur at the 45 minute point (to the closest 15 minutes) in an even-numbered negative hour, such as -20:45 or -24:45. TEI occurs over approximately the same point on the lunar surface but at the 15 minute point in an odd-numbered positive hour, such as +29:15 or +31:15. The events shown on the inner circle are those defined by the moon and lunar orbit geometry. Those on the outer circle are defined by the earth and lunar orbit geometry. As drawn, the diagram assumes a landing at the IIP-2 (prime target for G1) site. As landing sites change, however, the outer circle may be rotated to provide the correct relationship. It should be noted that the location of the terminator is defined, regardless of landing site, by lighting constraints (i.e., it is on the inner circle). Both communications and light/dark cycles are also available from this figure.

Associated with each fixed event is a specific block of time. Thus descent must immediately precede TD, and post-landing checkout must immediately follow TD. The block of time beginning with the initiation of descent (at undock) and terminating with the completion of postlanding checkout is a single unit which brackets TD and must appear, unbroken, in the timeline. The length of this block is a function of trajectory constraints and procedures, as discussed in section 3.3, but its existence as a unit is invariant. Similar blocks of time exist in association with LOI, LO, and TEI.

Two additional large blocks of time are "EVA" and "LM activation and checkout." EVA includes preparation and post EVA operations and must occur between TD and LO in a single block. LM activation and checkout differs in that it may be broken into more than one block of time. It must, however, precede descent and TD.

Six activities, each representing a relatively large time block, have been identified for inclusion in the work portion of the work/rest cycle. With the possible exception of portions of the LM activation and checkout, their order is fixed, as shown in Figure 3, and the rest portion of the work/rest cycle may only be inserted between these blocks. Thus the order of activities and specific points for the insertion of rest periods have been defined, and, together with the trajectory constraints summarized in Figure 2, timeline construction is relatively straightforward.

3.0 TIME BLOCKS

Some comments regarding the structure and duration of these activities are in order. As has been stated above the length of the individual time blocks is a function of procedures and trajectory constraints. Since the firmness of definition of these variables differs for each activity, the level of confidence with which a duration is specified for various activities also differs. The following discussion describes each activity briefly and indicates the flexibility associated with the length of time assigned to it and used in this analysis.

3.1 Lunar Orbit Insertion (LOI) Block:

This maneuver consists, actually, of two burns, each occurring at the same point, (see Figure 2) two revolutions apart. LOI₁ performs the insertion from trans lunar coast (TLC) to lunar orbit, placing the vehicle in an elliptical 60x170 nm orbit. The second, or "trim" burn, circularizes the orbit. Thus the time block associated with LOI is the four hours separating LOI₁ and LOI₂, plus a small amount of time required for the initial orbital insertion.

A certain amount of the time between the two burns is used in G&N sightings and precise orbital determinations in order to define parameters for the second burn. Some of this time may also be used for lunar familiarization, photography, eating, and general housekeeping. The efficiency of including other activities, such as LM activation and check-out, in this time period is relatively low, since preparation and restoration time associated with such tasks represents a large fraction of the total time available in this time block. It is, however, conceivable that such activities could be carried out in an efficient manner between LOI₁ and LOI₂, and, in fact, the slack inherent in this block acts as a backup mode in some of the specific timelines presented below. The two burn LOI block is depicted in Figure 4.

Much of this time may be saved by performing only a single LOI burn. The primary rationale for a two-burn LOI is that a "trim" burn will probably be needed anyway, and that deleting a burn from the timeline is much easier than adding one. In addition, uncertainties as to the shape and strength of the lunar gravitational field influence a decision to use the first two revolutions to refine orbital data and allow a more accurate circularization with the second burn. As will be discussed later, the advantage of a single burn is that the mission may be shortened by as much as 12 hours, alleviating concerns over time-critical factors such as super-critical helium pressure rise. Implicit in the use of a single

burn is the assumption that current knowledge and equipment sophistication will provide a sufficiently accurate lunar orbit without a "trim" burn.

Most of the timelines presented here use two LOI burns. However, any one of them is directly applicable to a single burn case by eliminating 4 hours between the burns, and possibly rescheduling an eat period. One set of timelines is specifically developed to take maximum advantage of a planned single burn, and the associated benefits are noted.

3.2 LM Activation and Checkout Block:

This time block is perhaps the most flexible and currently least defined. The specific items which must be checked, the monitoring which must accompany such checks, the time required to perform these activities, the consumables required, and the scheduling are all matters of study at this time, for which no clear set of optimum solutions is currently apparent. About all that can be agreed upon is that the LM must be activated and checked out to some extent, and that this process must precede descent. At least a portion of this activity must immediately precede descent, but whether the remainder may be accomplished at some separate, earlier time, perhaps even before LOI, remains a matter of debate.

It does seem clear that the LM must be powered up and put into operation at some time, and that, at the minimum, G&N, ECS, EPS, and communications must be checked out. In addition some parameters to assure operation of the RCS, DPS, and APS should be observed. Whether such systems checkouts should be monitored by MSFN is also a matter of debate. If such a constraint is accepted, only 1 1/4 hours of each revolution are available for systems checks.

A G&N constraint requires a landmark tracking of the intended landing site at the latest possible opportunity prior to undocking. Thus this activity must occur 1 1/2 hours before undocking or 2 hours prior to separation (see Figure 2). A docked LM IMU alignment in the night pass following the landmark tracking is also a current requirement. Since intravehicular transfer (IVT) interferes with the landmark tracking, which is performed in the CM lower equipment bay (LEB), the LM crew must be in the LM at that time. Thus as a minimal requirement, not considering full systems checks, the LM crew must be in the LM for the 2 hours preceding undocking. A prevalent estimate as to the time required for detailed systems checks is 4 hours⁽¹⁾. Adding the 2 hours discussed above, a 6 hour minimum duration of LM activation and checkout is obtained. In the timelines presented here a minimum of 4 1/2 hours is allowed for systems checks, giving a 6 1/2 hour total.

The most straightforward method of scheduling LM activation and checkout is to combine all 6 1/2 hours into a single block and schedule them immediately before descent. This is the method used in prime timeline A and its real time alternates. It imposes certain requirements and penalties upon the work/rest cycle, as will be discussed in section 4.1. A continuous 6 1/2 hour LM activation and checkout block is shown in Figure 5.

One method of alleviating these constraints is to split the LM activation and checkout into a 4 1/2 hour systems checkout and a separate 2 hour block preceding descent. This method of division provides for the major portion of the activity to be accomplished in the first section, with the second section reduced to an absolute minimum as defined above. This allows a sleep period to be scheduled between the two portions of checkout, the latest possible time before descent. This is the procedure used for prime timelines B, C, and D and their real time alternates. The question now arises, however, as to whether the LM may be left in a powered up, operating state between the two portions of checkout time. Not only are consumables used, perhaps causing depletion of the quantities available to an excessive extent, but the LM may be left unmonitored by the crew with systems running, leading to possible problems. The LM may, of course, be powered down while not inhabited, thus alleviating such problems, however such an action may partially invalidate the systems checks just completed. This would require at least a partial recheck of some systems upon reactivating the LM in the final 2 hour time block.

The resolution of this problem is not clear at this time⁽²⁾. The perfunctory checks required after powering down and reactivating the LM would appear to fit into the slack time included in the final 2 hour block. However, additional consumables are still used in this mode. A detailed consumables usage analysis of these modes, not performed here, is required to fully understand the tradeoffs involved and to validate the split LM activation and checkout approach.

3.3 Touchdown (TD) Block:

The descent timeline is defined backward from TD. Powered descent initiation (PDI) occurs (see Figure 2) 10° short of TD, and descent orbit insertion (DOI) occurs 180° before TD. Since TD is 7° from the terminator in the sunlight, this places DOI 7° in darkness. Undocking, LM inspection, and separation must occur in daylight, and this sequence requires approximately 30 minutes. Since the hour preceding DOI is in darkness, undocking must occur at least 1 1/2 hours prior to DOI. The hour between separation and

DOI provides an opportunity for a final LM IMU align and systems check, as well as preparation for DOI. Adding the hour between DOI and TD to the 1 1/2 hours between undock and DOI, as shown in Figure 2, descent requires 2 1/2 hours. Figure 6 illustrates the TD block of activities.

Optimum abort to orbit opportunities occur at 2 minutes and 2 hours after TD. Upon reaching the surface the crew performs a complete post landing systems check. They then verify systems for a possible LO at the 2 hour point. An actual countdown is exercised to just prior to actual ascent. This activity thus requires the full two hours following landing. The time block associated with TD, from undocking to completion of the postlanding check-out, then, is 4 1/2 hours long.

3.4 Extravehicular Activity (EVA) Block:

The nominal lunar surface EVA requires 3 hours⁽³⁾. One man egresses from the LM and spends about 1 hour on the surface prior to being joined by the second man. Both men spend the next two hours outside the LM. Provision is made, however, in the EVA timeline, for a real time decision to terminate the activity after two hours in case of crew fatigue or minimal consumables reserves in the Portable Life Support System (PLSS). For timeline planning purposes 3 hours must be provided for EVA. Additional time, however, is associated with the EVA time block.

Preparation for EVA requires such activities as donning helmet and gloves, attaching the PLSS and Oxygen Purge System (OPS), powering down some LM systems, and unstowing equipment for use on the lunar surface. Simulations of these activities in LM mockup MSC-16 in lg⁽⁴⁾ required between 1 and 2 hours. In the timelines presented here 2 hours are allotted for EVA preparation.

After EVA the LM must be powered up again and rechecked. The PLSS and OPS must be doffed, equipment stowed or jettisoned, and pre EVA status restored. Similar simulations of these activities⁽⁵⁾ have required just over 1 hour. Post EVA activities occupy 1 1/2 hours in the timelines developed here.

The total block of time associated with EVA, including pre and post EVA operations consumes 6 1/2 hours, as shown in Figure 7. This includes all activities on the lunar surface associated with manned operations outside of the LM.

3.5 Lift Off (LO) Block:

Nominal (optimum) opportunity for LO occurs, as shown in Figure 2, at 2 hour intervals after TD. The post-landing checkout devotes part of its time to preparing for the first such opportunity. Preparation for LO at any other time repeats a portion of this procedure, as well as a few additional operations. The timelines presented here devote at least 1 1/2 hours to LO preparation.

The nominal timeline must schedule LO, and the completion of LO preparation, at some multiple of the 2 hour launch opportunity cycle after TD. Ascent, which begins at this point and ends with the completion of docking requires 3 1/2 hours⁽¹¹⁾ (see Figure 2). After docking, equipment and samples to be returned to earth are transferred to the CM, the LM is deactivated, the crew returns to the CM, and the hatch is closed to seal off the LM. Simulations of this intravehicular transfer (IVT) are in progress to refine the estimated 2 hours⁽⁶⁾ required for operation.

The block of time beginning with LO preparation and ending with the deactivated, sealed off LM, as shown in Figure 8, requires a total of 7 or 7 1/2 hours. This time requirement is somewhat less well defined and slightly more flexible than that associated with TD.

3.6 Trans Earth Injection (TEI) Block:

As was mentioned previously TEI occurs at the same point as LOI and may be scheduled in the manner described using Figure 2. As illustrated in Figure 9, LM jettison and preparations for TEI require 2 hours⁽⁶⁾, and post TEI operations are assumed to take a minimum of 2 hours, although the exact time required is not critical for planning purposes. Thus the TEI time block takes a minimum of 4 hours.

3.7 Don/Doff Pressure Garment Assembly (PGA) Block:

The PGA is donned and doffed in the CM, and worn during descent, ascent, and the entire lunar surface stay. The activity is a sequential operation, with only a single crew member performing a donning or doffing in the LEB at a time. Ground simulations indicate that the donning operation is quite time consuming, requiring 30 minutes per crew man or more. Recent zero g experience on Apollo 7 and Apollo 8 has revised the estimate to 10 minutes per man or less. Doffing requires about half the time necessary for donning. PGA donning is allotted 1 hour and 1/2 hour is provided for doffing in the timelines presented.

3.8 Eat Block:

Time is provided for eating after every 6 to 8 hours of other activities. Each block for eating is 1 hour in length. Since the actual process of eating does not require a full hour, this period provides the time required for personal hygiene and general housekeeping chores. Experience indicates that eating and personal hygiene activities rarely occur as per schedule. These scheduled blocks, therefore, represent slack to accomodate the actual occurrence of these events.

Since the inclusion of a 1 hour eat block is required every 6 to 8 hours, most of the major activities discussed above are operationally 1 hour longer than indicated. Thus, for planning purposes the 6 1/2 hour EVA block must be considered to consume 7 1/2 hours when the required eating allotment is included.

3.9 Rest Block:

Nominal timelines are planned to provide approximately a 16/8 work/rest cycle. This reflects an attempt to maintain the customary periodicity of a normal 24 hour earth day. In theory it also maintains the earth-based diurnal cycles or circadian rhythms in their 24 hour periodicity.

The available evidence⁽⁷⁾ indicates that performance during the work portion of the cycle improves as sleep duration increases from 1 to 6 hours. Between 6 and 8 hours of sleep provides little demonstrable increase in level of performance, although there appears to be some feeling of "well being" attained. Sleep beyond 8 hours duration in a 24 hour cycle results in no improvement of performance. Accordingly, for the timelines presented here, a minimum of 6 hours and a maximum of 8 hours of sleep were used as the flexibility limits of the 16/8 cycle.

During a normal 16/8 work/rest cycle, efficiency is lowest upon arising, increases sharply to a plateau after about 4 hours, and begins to drop about 4 hours before retiring⁽⁸⁾. Thus ideally the most difficult tasks to accomplish should be scheduled during the middle of the work period. Of course other factors, such as task loading, motivation, and danger affect the level of performance significantly.

Studies of sleep deprivation indicate⁽⁹⁾ a sequence of progressive performance deteriorations as a function of increased sleep deprivation. Detection of visual targets (e.g., acquiring the CSM during rendezvous) is one of the first functions to degrade, followed by an increased time requirement for decision making (e.g., reaction time for emergencies), and then operational error (e.g., DSKY mis-punch). None of these is incapacitating, but all do involve increased risk. Degradations of mental capacity, such as the ability to do arithmetic problems, do not appear to be significant until 40 hours of continuous wakefulness.

The sanctity of a 16/8 work/rest cycle is not clearly established, although it minimizes risk by adopting an accepted and thoroughly tested standard. Although the advantages or disadvantages of other possible cycles, such as 8/4 or 4/4 will not be discussed here, their possible merit does bear further scrutiny. References 7 and 10 review this area thoroughly.

4.0 TIMELINES

Four primary, or nominal, possible timelines are developed. Each fulfills the requirements set forth above in its planned form and deviates from the work/rest cycle constraints in its real time alternates, which represent unplanned (but preconsidered) decisions by the crew to postpone designated sleep periods. Thus each real time alternate reflects the benefits and penalties of real time decisions to modify the preplanned nominal timeline, and the family of alternates may be taken as an indication of the real time flexibility of the nominal timeline.

As discussed above and illustrated in Figure 3, opportunities to sleep come only at discrete intervals, before or after fixed blocks of activities. Table 1 summarizes some possible work/rest configurations in a decision matrix. Each combination refers to a specific timeline presented here.

Two alternative LM activation and checkout periods are considered, one before LOI and the other after LOI. An asterisk (*) in Table 1 indicates the option chosen for a specific timeline. A final LM activation and checkout period always precedes descent. A sleep period is designated by an "S" below the timeline between the events which bracket it. When a real time decision is made not to sleep at a planned time an "N" indicates such an action.

4.1 Timeline A and Alternates:

The timeline identifications, organized into four families, are shown in the first column of Table 1. Timeline A is the nominal, preplanned version of the first family, and Ala, Alb, and A2 represent its real time alternates. It is clear from the chart that family A is characterized by sleep in lunar orbit prior to LM activation and sleep on the surface nominally before EVA as a result of the 16/8 work/rest constraint. Similarly, sleep is also nominally scheduled in orbit before TEI.

Real time alternate Ala indicates the result of a real time decision not to sleep before TEI. This might result from crew apprehension as to whether the SPS will perform properly and their desire to find out prior to sleeping. The consequence of this decision is to move the scheduled time for sleep to immediately after the TEI block.

In a similar fashion the crew might decide to postpone the scheduled sleep period before EVA, a not unlikely possibility on the first lunar landing mission. Real time alternate Alb addresses this possibility and shows the sleep schedule slippage to before LO and the resulting transfer of a sleep period from before to after TEI. The dual decisions not to sleep on the lunar surface at all are reflected in real time alternate A2. These four timelines are presented in detail in the appendix.

The most significant advantage of the A family of timelines is the scheduling of LM activation and checkout in a single block immediately preceding descent. This allows the scheduling of active LM time including only one sleep period. Assuming that the LM must be left activated during sleep, the A family provides the minimum usage of LM consumables.

The penalty associated with the plan is a relative loss of real time flexibility. That is, it practically requires a sleep period on the lunar surface. Only real time alternate A2 provides for no sleep on the surface, and the associated penalty is a 31 hour work period. Yet the probability of the crew being uncomfortable and nervous about sleeping in a very novel environment is not negligible. A further discussion of the tradeoffs between timelines is presented in section 5.

4.2 Timeline B and Alternates:

Timelines B, C, and D and their alternates all involve split LM activation and checkout, with the larger portion occurring prior to sleep and a shorter system check preceding descent. Timeline B and its real time alternates, shown in detail in the appendix, all perform the first stage of LM activation and checkout immediately after LOI. A sleep period precedes the final orbital activities before descent. As a result of the orbital sleep period scheduled in such proximity to descent the nominal surface sleep can follow EVA.

A number of advantages accrue from this configuration. The nominal timeline calls for the next sleep following TEI, thereby eliminating a real time "no sleep before TEI" decision as could occur with timeline A (real time alternate A1a). Timeline B also reduces the nominal number of sleeps in the lunar environs from 3 to 2, thereby reducing the CSM time in lunar orbit.

With this family of timelines the decision not to sleep on the lunar surface (real time alternate B1) is a single, rather than double, decision with a penalty of only 25.5 awake hours, rather than the 31 associated with a similar mode in alternate A2. The dual decision shown in alternate B2, not to sleep on the surface and to postpone the resulting sleep before TEI has an associated 30.5 hour awake penalty, but significantly reduces both CSM lunar orbit and LM lunar surface times.

Since the time between initial LM activation and final LM deactivation is increased by one sleep period in timeline B over timeline A either consumables must be sufficient to accommodate this increased operative time or the LM must be at least partially deactivated during the extra sleep period. This problem has been discussed in section 3.2. Other tradeoffs will be presented in section 5.

The real time alternates C1, C2, D1, and D2 involve real time decisions identical to those for B1 and B2, with similar benefits. They will, therefore, not be discussed in detail.

4.3 Timeline C and Alternates:

Timeline C and its real time alternates are presented in detail in the appendix. This family differs from family B in that LM activation and checkout has been shifted

to before LOI. In this case the time between LOI_1 and LOI_2 represents slack which can be used to complete any LM activation and checkout activities not accomplished during the prescribed period. Not only does this configuration allow more time for a leisurely checkout, but it reduces CSM lunar orbit time even further. If this timeline is to be accepted it must be assumed that the insertion maneuver does not invalidate previous LM system checks.

4.4 Timeline D and Alternates:

Additional benefits are gained by the consolidation of LOI into a single burn, as shown for the D family of timelines in the appendix. A single LOI maneuver not only eliminates the 4 hours required for the dual burn mode, but allows the last sleep period before descent to occur before LOI. This reduces CSM lunar orbit time to an even lower value and increases the awake times by only 1 hour over family C. A more detailed analysis of this type of tradeoff may now be presented.

5.0 TRADEOFFS

A time matrix, as shown in Table 2, may now be used to analyze the advantages and disadvantages of the detailed timelines developed above. The upper portion of the matrix indicates the length of time between two fixed events that define an activity of interest. The lower portion of the matrix presents an index of performance by assuming that the amount of time since the last opportunity to sleep may be used as an indicator of crew performance level. The time since sleep is shown for specific events which require high performance levels.

From Table 2 it can be seen that the four nominal timelines all provide close to the desired 16/8 work/rest cycle, and the maximum time awake in all plans is about the same. The single "no sleep" decision real time alternate timelines all involve approximately a full day without sleep. The double "no sleep" decision real time alternates require approximately 30 continuous hours awake.

The A family of timelines, as designed, minimize the time from initial LM activation to final LM deactivation, thereby reducing consumables problems. If consumables are adequate or if partial or complete intermediate LM deactivation are acceptable the B, C, and D timelines are more attractive. It should be noted, also, that real time alternates B1 and D1 provide LM continuously active times similar to A, Ala, and Alb, but at the penalty of a full day awake.

The A family of timelines requires the longest CSM period in lunar orbit. Families B, C, and D provide, as designed, progressively shorter times in orbit, thereby decreasing total mission time. It is interesting to note that timeline D reduces lunar orbit time, and thus mission time, by more than a day over that required by timeline A. Each set of real time alternates, with their inherent performance penalties, provide CSM lunar orbit stay time in the same range as the planned timeline in the next family. Thus the 54 hour orbital time of timeline B is matched by alternate Ala, but at the cost of a 23.5 hour maximum awake time.

5.1 Evaluation of No Sleep on the Surface Alternates:

All four nominal timelines call for sleep on the lunar surface and thus require approximately 20 hours surface stay time. In timeline A sleep is before EVA, and in timelines B, C, and D sleep is after EVA. By eliminating sleep on the surface, all the real time alternates to timelines B, C, and D provide the minimum lunar surface stay time of 12 hours, whereas alternates Ala and Alb still require 22 hours on the surface. Of the A family, only timeline A2, with a 31 hour awake time penalty, provides the 12 hour, no-sleep lunar surface stay. Timelines B, C, and D can, therefore, tolerate to a reasonable degree a real time decision to avoid sleeping on the lunar surface. Timeline A cannot do so without a large maximum time awake with the resulting decrement in performance.

Real time alternates B2, and C2, and D2 represent decisions not to sleep on the lunar surface or in orbit preceding TEI. The resulting penalty is a very long awake time on the order of 30 hours. A similar real time decision not to sleep on the surface or in orbit before TEI for family A is so unreasonable that it is not even presented.

5.2 Performance at TD and Docking:

The projected levels of performance can be more closely examined in the lower portion of Table 2. Four activities, critical in the aspects of coordination, timing, or judgement, or a combination of these, are considered in terms of time since the last sleep before the activity. As is shown, all nominal timelines provide reasonable awake times previous to each activity.

Timelines B, C, and D perform the two most critical maneuvers - landing and docking - 6.5 to 7.5 hours after sleep. Timeline A, however, requires a 12 hour awake period before landing and 14.5 hours before docking, indicating the possibility of a lower level of performance during these maneuvers.

Real time decisions not to sleep on the lunar surface result in a 27.5 hour awake time at docking for family A (alternate A2), 22 hours awake at docking for all the family B and C alternates, and 23 hours awake at docking for family D. No real time decisions not to sleep are considered prior to TD, and thus the prime and alternate timelines do not differ in TD awake times.

5.3 EVA Performance:

What will possibly be the most physically demanding activity, EVA, occurs 3 hours after sleep in timeline A, while timelines B, C, and D schedule the event about 12 hours after resting. However, if the real time decision not to sleep before EVA is made (alternate A1b), 17 hours awake precede the EVA, whereas the nominal plan for the other timelines provides that capability with no penalty.

5.4 Performance at TEI:

TEI is probably the least critical of the four activities in terms of physical requirements upon the crew. The dual decisions not to sleep on the surface and not to sleep before TEI (real time alternates B2, C2, and D2) result in this task being performed after about 28 hours awake, a large but not impossible penalty. The accruing benefit is an 8 hour reduction in mission duration, as indicated in the CSM lunar orbit times. As stated above, such an option is so unrealistic as to be eliminated from consideration in family A.

5.5 Overall Performance Evaluation:

An effort was made to combine these four indicators into a single value for each timeline. As a result each "time since sleep" value was evaluated on the scale:

$t \leq 4$	acceptable	0 points
$4 < t \leq 12$	desirable	+1 point
$12 \leq t \leq 16$	acceptable	0 points
$16 < t < 24$	undesirable	-1 point
$t \geq 24$	very undesirable	-2 points

based upon the criteria described in section 3.9 regarding performance level cycles during awake periods. The individual values were totaled for each timeline and are presented in the bottom line of Table 2.

To the extent that this rating scheme can be considered a good indicator some evaluations can be made. Timeline A can be considered acceptable, and the real time decision to defer the sleep before EVA to after EVA (alternate Alb) does not change its rating. The decision not to sleep before TEI (alternate Ala) is undesirable, and the no sleep on the surface alternate, A2, has a totally unacceptable performance rating. Timelines B and C appear to be very desirable, and their alternates which provide for no sleep on the lunar surface are still in the desirable category. This indicates that the B and C families provide a greater degree of flexibility than A, since their real time alternates still have high performance ratings. Even the no sleep on the surface or before TEI options, B2 and C2, are within reasonable limits. Family D does not fare quite as well as B and C, but considerably better than family A, and provides greater benefits than A.

6.0 CONCLUSION

Four tools for the construction and analysis of timelines have been developed and demonstrated. The trajectory constraint diagram (Figure 2) allows the trajectory-restricted events to be properly scheduled. The decision matrix (Table 1) permits the possible work/rest alternatives to be isolated and displayed. The time matrix (Table 2) provides a framework within which these alternatives may be compared and contrasted. Finally the performance rating system may be used as a rough measure of the overall advantage of a particular timeline from the point of view of performance during critical activities. Together they form a workable methodology.

6.1 Areas for Further Study:

Although the analysis presented here focussed on the lunar environs timelines for the first lunar landing mission, the tools are not so limited in their applicability. The methods may be used for the construction and analysis of any timeline which has the similar characteristics of fixed sequential events with associated activities. As such the methodology forms, in the broad sense of the word, a generalized timeline model. Its direct application to G2, the second lunar landing mission, is in order.

As has been stated, a number of areas of direct bearing upon these timelines have not received detailed attention here. The question of consumables usage obviously has a direct bearing upon the validity of the conclusions

reached. A systematic study of the feasibility of these timelines from a consumables point of view is a prerequisite to the adoption of a specific configuration. The use of a split LM activation and checkout, in particular, requires analysis of additional consumables required.

The detailed procedures utilized within each of the time blocks were also not considered directly. Clearly these have a significant effect upon the timelines since the duration of an activity is an additive function of the specific tasks and procedures which comprise that block. The procedures are interrelated, also, with consumables, since a procedural modification may significantly affect consumables usage with no timeline impact at all. A prime example of this, of course, is the power savings obtained by the procedural decision to power down the LM between portions of a split LM activation and checkout.

Only a single work/rest cycle - 16/8 - has been considered here. A similar analysis with alternate cycles may reveal even more attractive timeline configurations. The advantage of any particular work/rest cycle was not discussed extensively, and the interaction between the 16/8 cycle and the diurnal cycle was only treated marginally. It was assumed that the work/rest cycle and the earth-based circadian rhythm would either coincide, or would bear only a small penalty for being out of phase. More consideration of possible constraints arising from this area is in order.

The sensitivity of these timelines to abort requirements has not been treated directly. From Table 2, however, it can be seen that from a performance standpoint the A family of timelines are weakest for aborts immediately after TD, and the remaining families weakest for aborts following EVA. Real time alternates B1, C1, and D1 do reflect the results of an abort after EVA. If descent aborts are considered more probable than aborts after EVA, timeline A, with sleep before EVA, would be less desirable. However, any conceivable timeline has, by definition, its own strong and weak areas in terms of time since sleep for abort. Detailed analysis of abort sensitivity requires knowledge of abort probabilities at specific points in the timeline.

6.2 Recommendations:

One of the specific advantages of this timeline analysis methodology is that it reveals those areas in which relatively minor modifications can yield major benefits in

the overall timeline. Thus it allows detailed procedural analysis to be concentrated upon those areas from which the maximum benefit may be expected. This iterative interaction allows the ultimate development of one optimum timeline. This analysis has identified LM activation and checkout as an activity which critically affects flexibility of the timeline in the lunar environs. The split LM activation and checkout, with emphasis upon the minimization of the second portion, provides additional capability for real time modification of the succeeding timeline with minimum impact upon performance, as demonstrated in the B family of timelines. Scheduling the first portion of this checkout before LOI (family C) permits the same real time flexibility with reduced CSM time in lunar orbit and consequent reduction of mission duration. A further reduction of 12 hours in mission duration is obtained (see section 4.4) by using a single burn LOI (family D). Thus a possible 26 hour savings in mission time between nominal timeline A and nominal timeline D (see Table 2) with added real time flexibility provided, becomes apparent with the use of this methodology.

Table 3 combines the data presented in the decision matrix and time matrix to summarize the salient points in this analysis. Nominal timelines B, C, and D, with their matching alternates, provide greater real time flexibility with less performance penalty than timeline A. They also provide the minimum lunar surface stay time option with low performance penalty. As such they bear a distinct advantage over timeline A and its real time alternates. To obtain these benefits, however, the split LM activation and checkout, with full systems checks included in the first portion of checkout, as discussed in section 3.2, must be adopted.

Nominal timelines B, C, and D also provide the probability of best performance during the two most critical maneuvers, in terms of timing, judgment, and coordination, TD and docking. Timeline A, on the other hand, provides a somewhat more rested crewman for EVA. Its real time alternate Alb, however, provides the least rested EVA crewman, due to the decision to defer sleep before EVA.

The conclusions reached here are based on the methodology which was developed and used to portray the advantages and disadvantages of each family of timelines, and to discuss the relative tradeoffs. Some specific parameters - time in lunar orbit, time on the surface, real time flexibility, and performance levels - have been maximized or minimized in individual timelines. To some extent weights have been

associated with these parameters to perform the evaluation above. The methodology raises the pertinent questions and indicates possible answers. The conclusions drawn are dependent upon the subjective evaluation and parameter weighting. With the weighting used here, however, it appears that a split LM activation and checkout with sleep after EVA provides the best probability of high crew performance levels and the most flexible timeline in the lunar environs.

A handwritten signature in black ink that reads "Peter Benjamin". The signature is fluid and cursive, with the first name "Peter" and last name "Benjamin" clearly distinguishable.

P. Benjamin

2033-PB-gdn

Attachment
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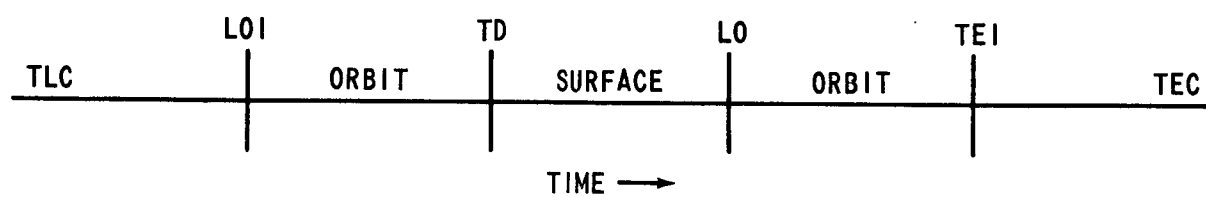


FIGURE 1 - FIXED EVENTS IN THE LUNAR ENVIRONS

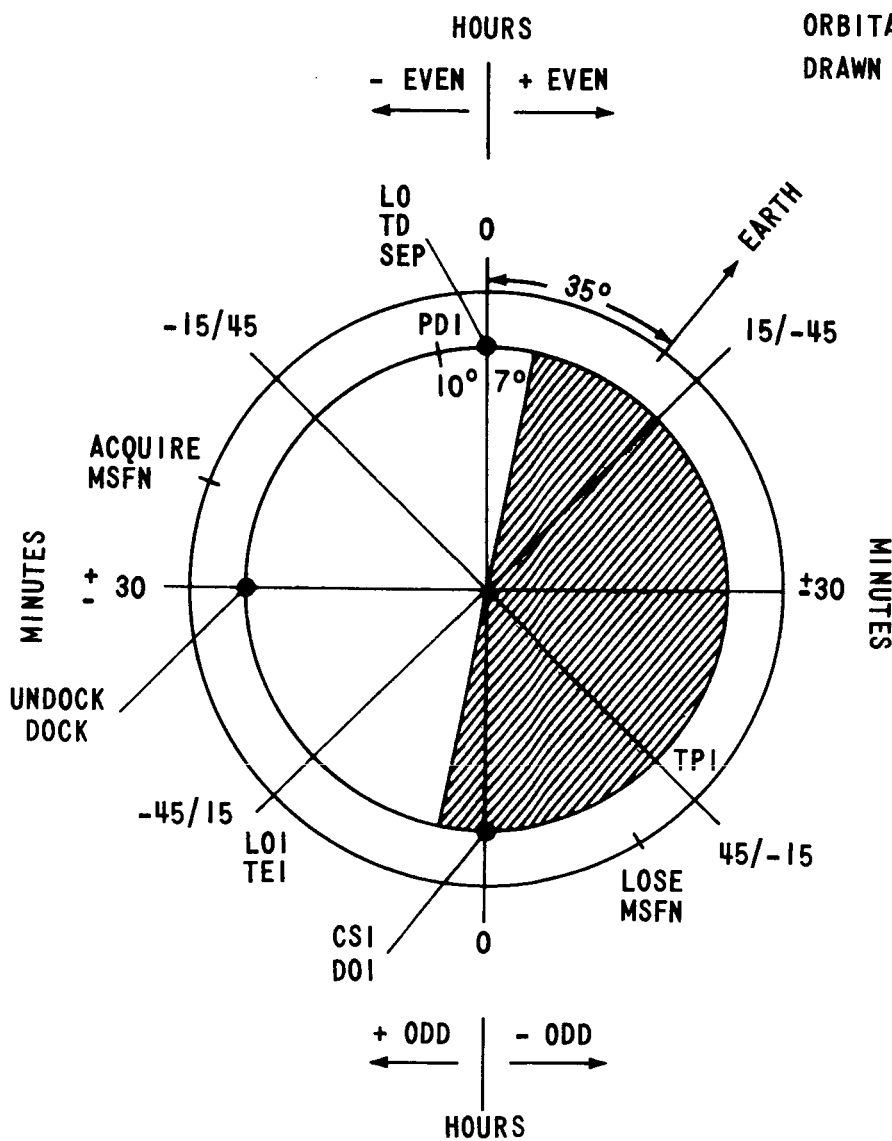


FIGURE 2 - TRAJECTORY CONSTRAINTS

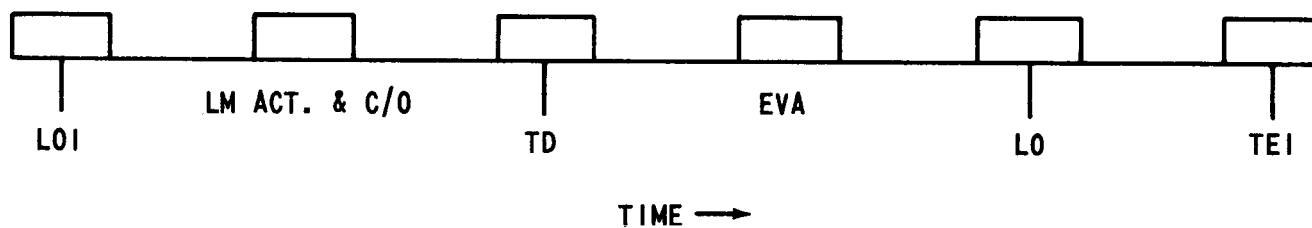


FIGURE 3 - LUNAR ENVIRONS ACTIVITIES

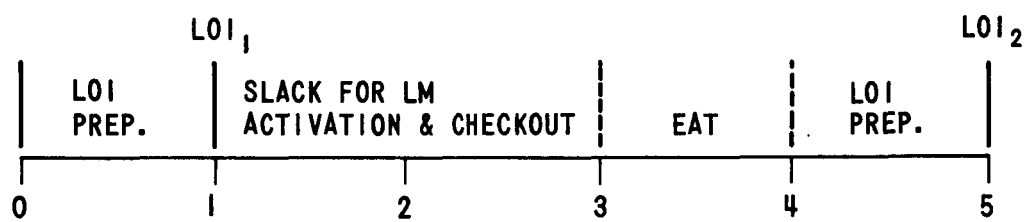


FIGURE 4 - LOI TIME BLOCK

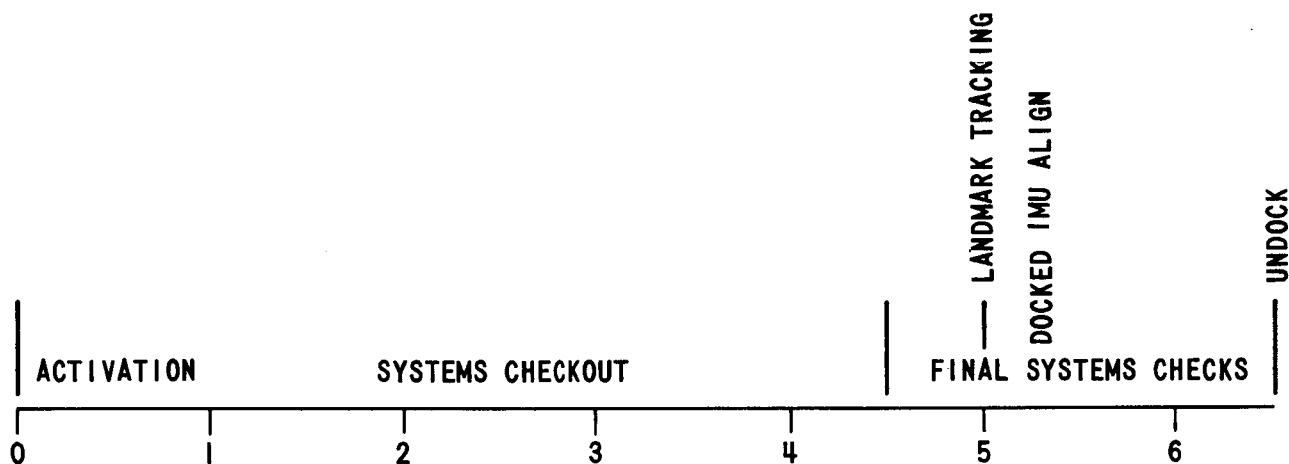


FIGURE 5 - LM ACTIVATION AND CHECKOUT

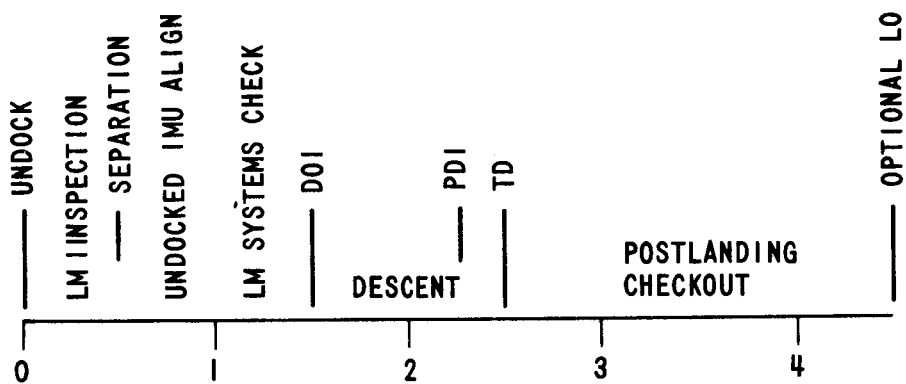


FIGURE 6 - TD TIME BLOCK

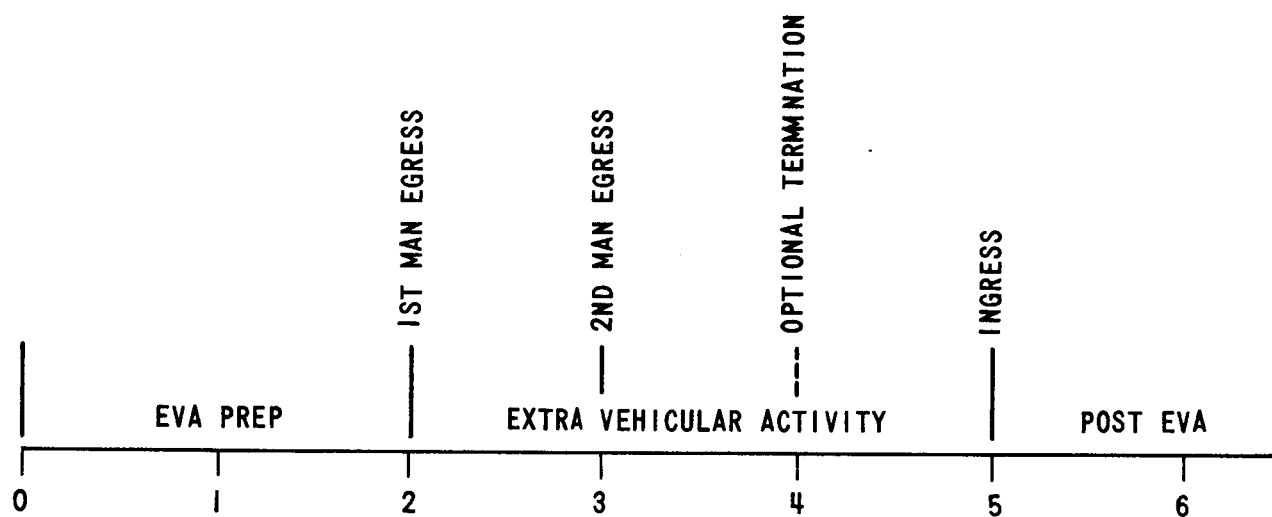


FIGURE 7 - EVA TIME BLOCK

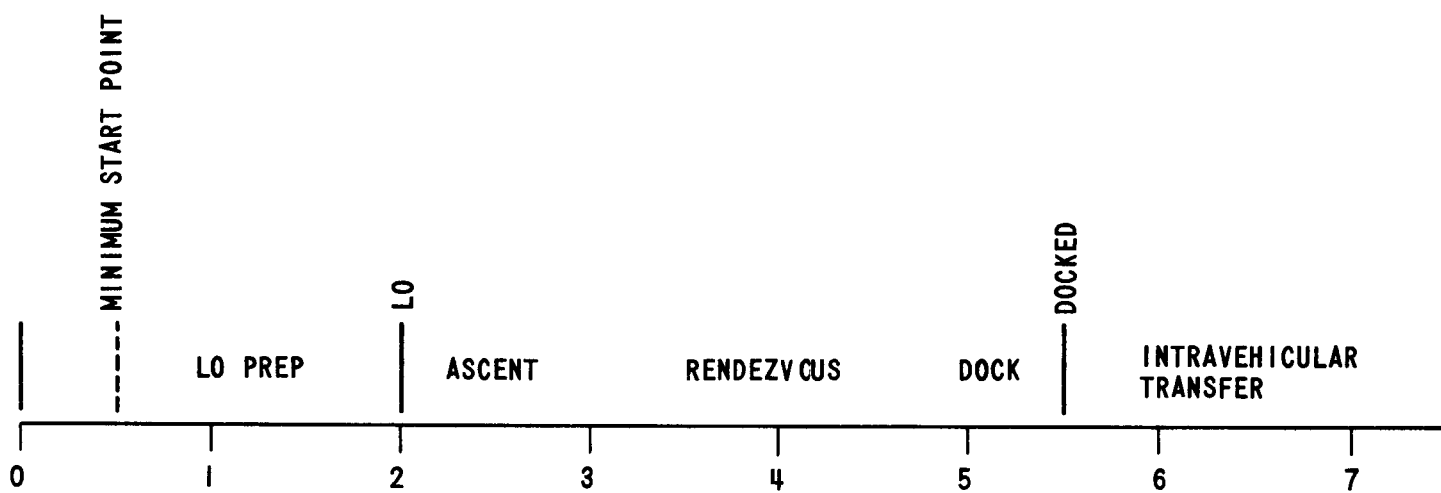


FIGURE 8 - LO TIME BLOCK

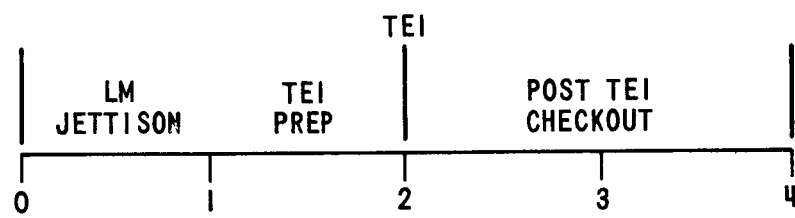


FIGURE 9 - TEI TIME BLOCK

TABLE I - DECISION MATRIX

TIMELINE	(LM ACT.)	LOI	(LM ACT.)	LM ACT.	TD	EVA	LO	TEI
A		S	*			S		S
A1a		S	*			S		N
A1b		S	*			N	S	
A2		S	*			N	N	S
B			*	S			S	
B1			*	S			N	S
B2			*	S			N	N
C	*		S				S	
C1	*		S				N	S
C2	*		S				N	N
D	*	S					S	
D1	*	S					N	S
D2	*	S					N	N

* - DESIGNATED LM ACTIVATION AND CHECKOUT PERIOD

S - SLEEP PERIOD

N - DECISION NOT TO SLEEP AT THIS POINT

TABLE 2 - TIME MATRIX

TIMELINE	A	A1a	A1b	A2	B	B1	B2	C	C1	C2	D	D1	D2
MAX. TIME AWAKE	18	23.5	22.5	31	17	25.5	30.5	17	25.5	30.5	18	26.5	31.5
TIME FROM INITIAL LM ACT. TO FINAL LM DEACT.	37.5	37.5	37.5	27.5	46.5	38.25	38.25	52.5	44.5	44.5	47.5	39.5	39.5
CSM TIME IN LUNAR ORBIT	62	54	54	52	54	54	46	48	48	40	36	36	28
TIME ON LUNAR SURFACE	22	22	22	12	20	12	12	20	12	12	20	12	12
PERFORMANCE: TIME SINCE SLEEP													
FOR TD	12	12	12	12	6.5	6.5	6.5	6.5	6.5	6.5	7.5	7.5	7.5
FOR EVA	3	3	17	17	11.5	11.5	11.5	11.5	11.5	11.5	12.5	12.5	12.5
FOR DOCKING	14.5	14.5	7	27.5	6.5	22	22	6.5	22	22	6.5	23	23
FOR TEI	3.25	20.75	12.75	3.75	12.25	3.25	27.75	12.25	3.25	27.75	12.25	3.25	28.75
PERFORMANCE RATING	0	-1	0	-3	+3	+1	-1	+3	+1	-1	+2	0	-2

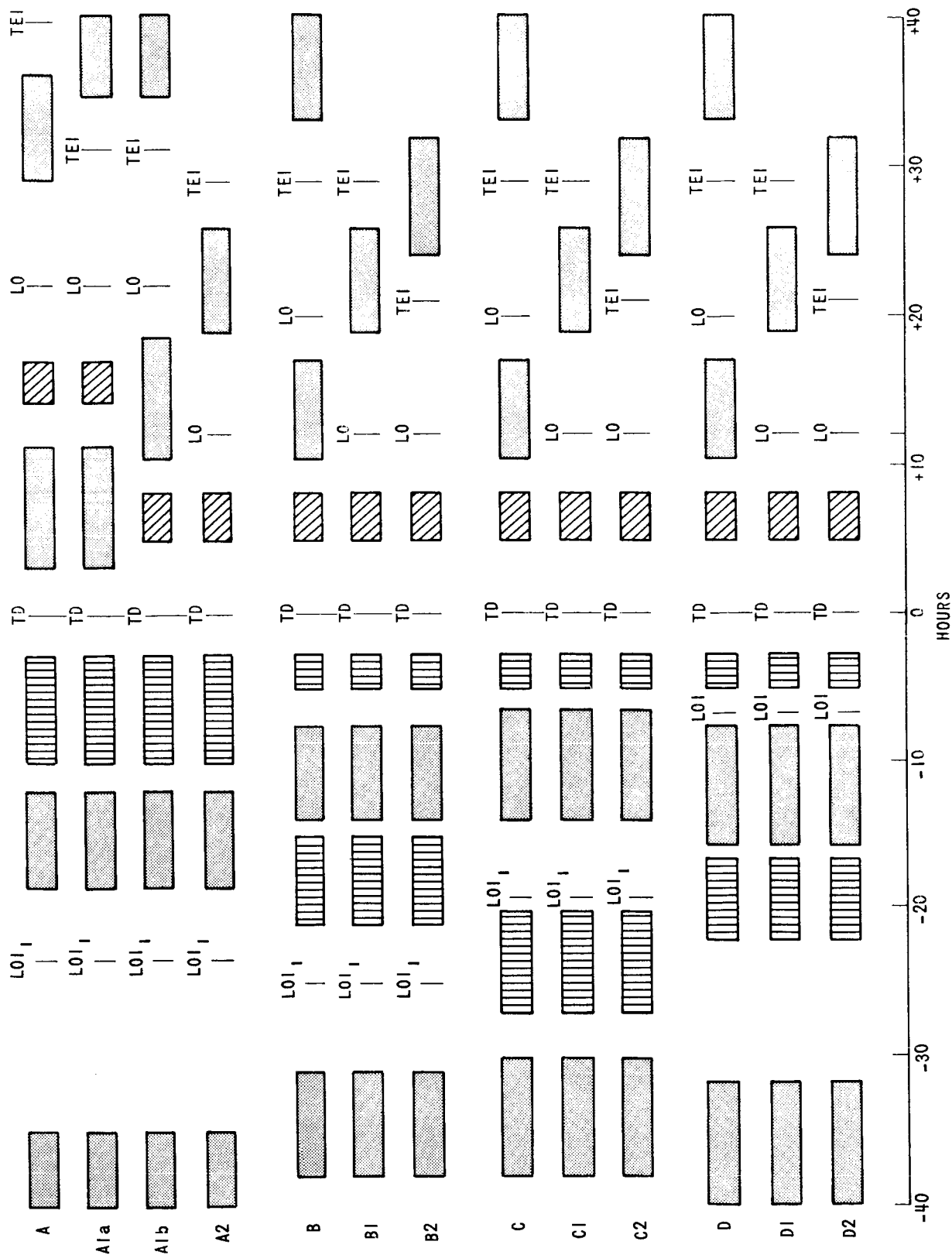
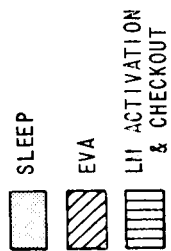
TIMELINE OR ALTERNATE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
A	SINGLE LM ACTIVATION AND CHECKOUT • SLEEP BEFORE EVA	<ul style="list-style-type: none"> • MINIMUM LM CONSUMABLES USAGE • MOST RESTED PRIOR TO EVA 	<ul style="list-style-type: none"> • LEAST REAL TIME FLEXIBILITY • MAX. TIME IN ORBIT (62 HRS.)
A1a	SAME AS A EXCEPT: • NO SLEEP BEFORE TEI	<ul style="list-style-type: none"> • REDUCES TIME IN ORBIT (54 HRS.) 	<ul style="list-style-type: none"> • 21 HOURS AWAKE AT TEI
A1b	SAME AS A EXCEPT: • SLEEP AFTER EVA IN-STEAD OF BEFORE	<ul style="list-style-type: none"> • PROVIDES EARLY EVA 	<ul style="list-style-type: none"> • 17 HOURS AWAKE AT EVA
A2	SAME AS A EXCEPT: • NO SLEEP ON SURFACE	<ul style="list-style-type: none"> • MINIMUM SURFACE STAY TIME • REDUCES TIME IN ORBIT (52 HRS.) 	<ul style="list-style-type: none"> • 31 HOURS MAX. AWAKE TIME • 27.5 HOURS AWAKE AT DOCKING
B	SPLIT LM ACTIVATION AND CHECKOUT • SLEEP AFTER EVA	<ul style="list-style-type: none"> • MOST REAL TIME FLEXIBILITY • PROVIDES EARLY EVA • MOST RESTED AT TD • MOST RESTED AT DOCKING • REDUCES TIME IN ORBIT (54 HRS.) 	<ul style="list-style-type: none"> • 11.5 HOURS AWAKE AT EVA
B1	SAME AS B EXCEPT: • NO SLEEP ON SURFACE	<ul style="list-style-type: none"> • MINIMUM SURFACE STAY TIME 	<ul style="list-style-type: none"> • 22 HOURS AWAKE AT DOCKING
B2	SAME AS B1 EXCEPT: • NO SLEEP BEFORE TEI	<ul style="list-style-type: none"> • REDUCES TIME IN ORBIT (46 HRS.) 	<ul style="list-style-type: none"> • 31 HOURS MAX. AWAKE TIME • 28 HOURS AWAKE AT TEI

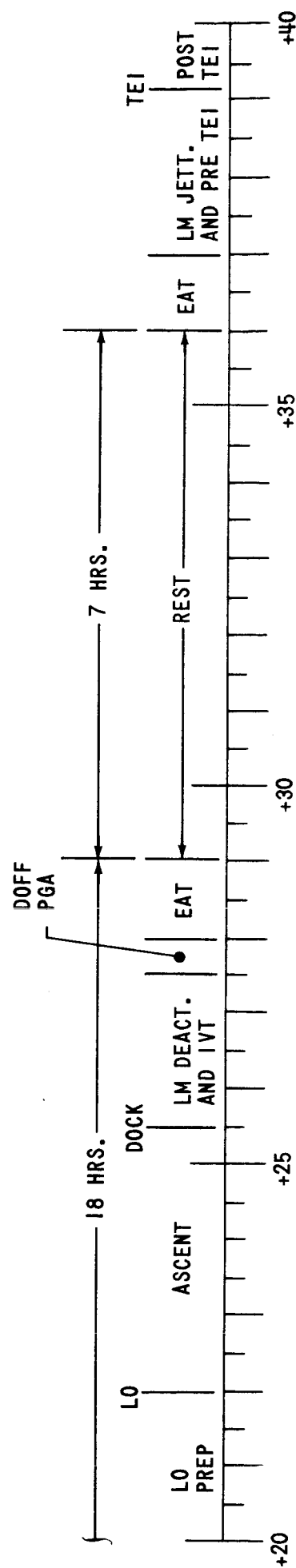
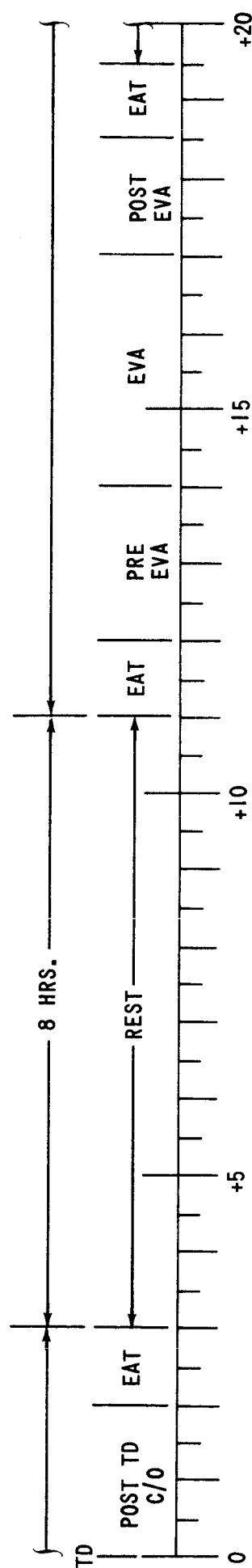
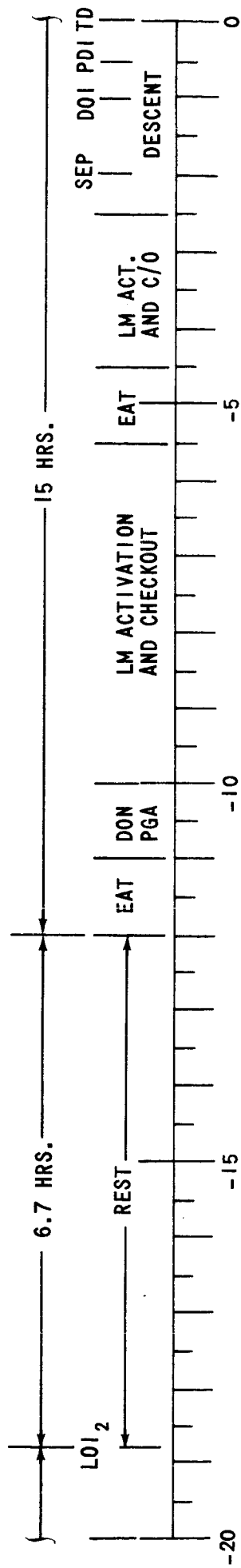
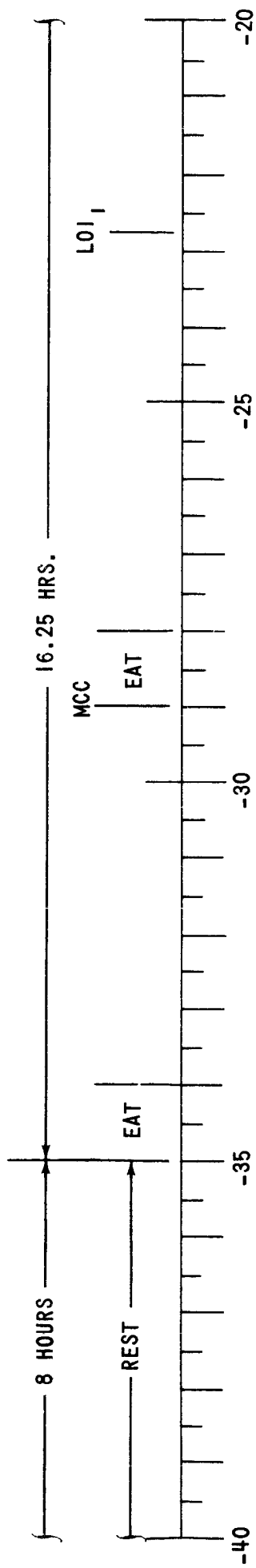
TABLE 3 - TIMELINE CHARACTERISTICS

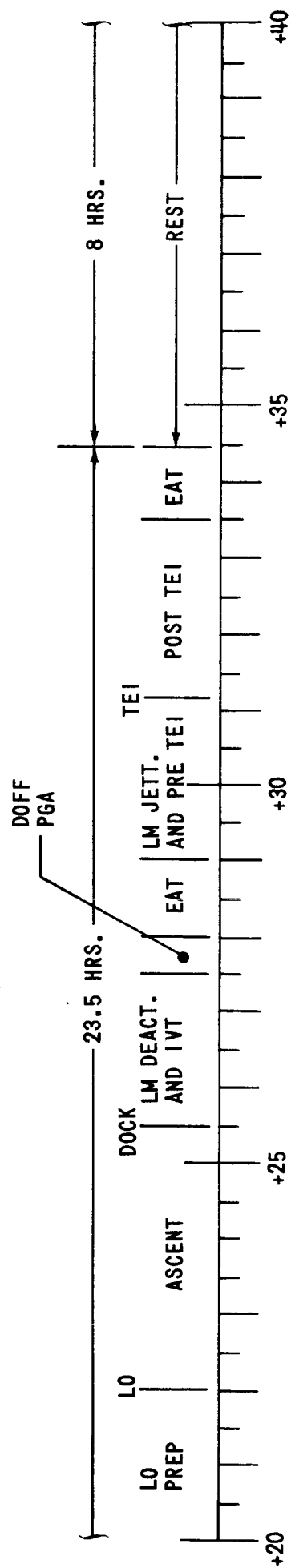
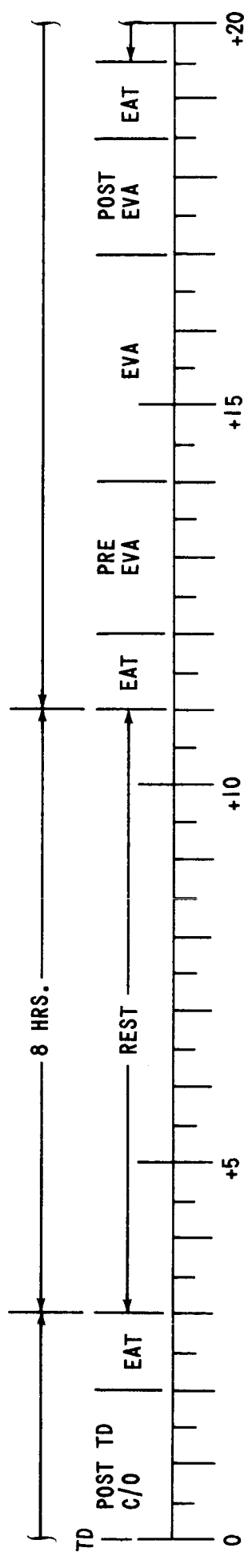
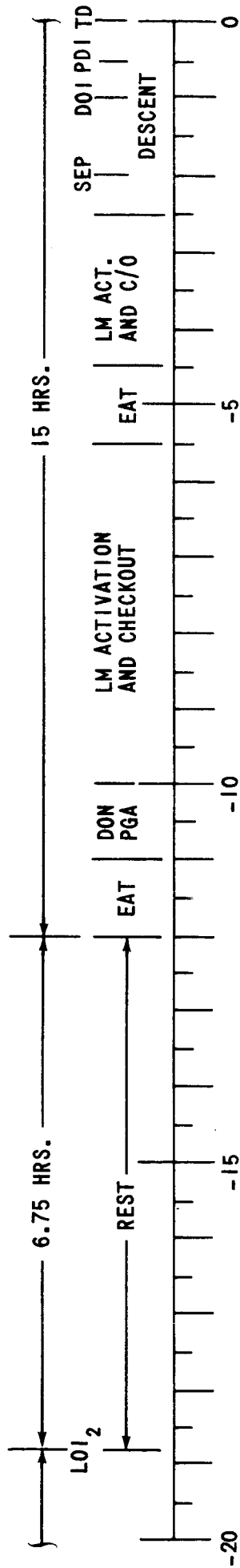
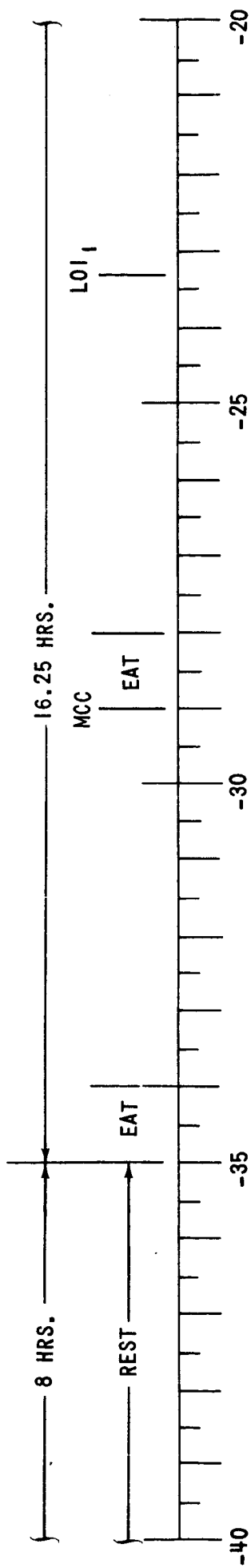
TABLE 3 (CON'T)

C	SAME AS B EXCEPT: • LM ACTIVATION AND CHECK- OUT BEFORE LOI	• REDUCES TIME IN ORBIT (48 HRS.)	• LOI MAY INVALIDATE LM CHECKOUT
C1	SAME AS C AND B1		
C2	SAME AS C AND B2	• 40 HRS. IN ORBIT	
D	SAME AS C EXCEPT: • SINGLE BURN LOI • NO SLEEP IN ORBIT PRIOR TO DESCENT	• REDUCES TIME ORBIT (36 HRS.)	• DOES NOT ALLOW FOR LOI TRIM BURN
D1	SAME AS D AND B1		
D2	SAME AS D AND B2	• 28 HRS. IN ORBIT	

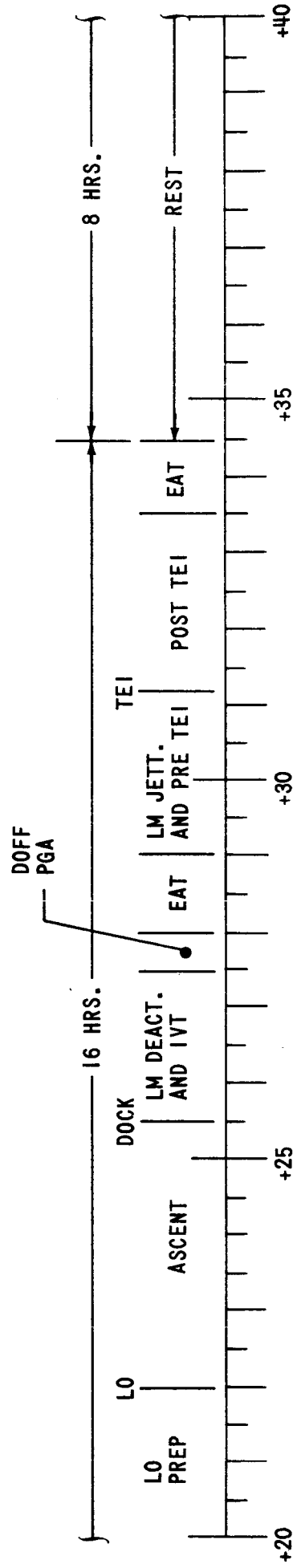
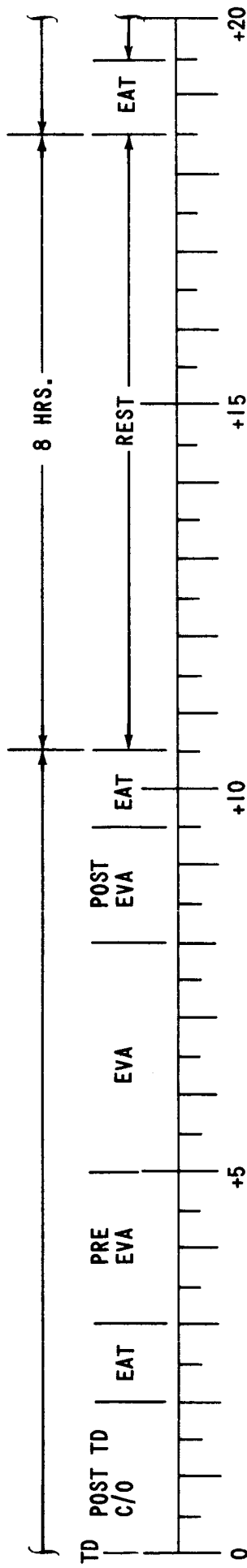
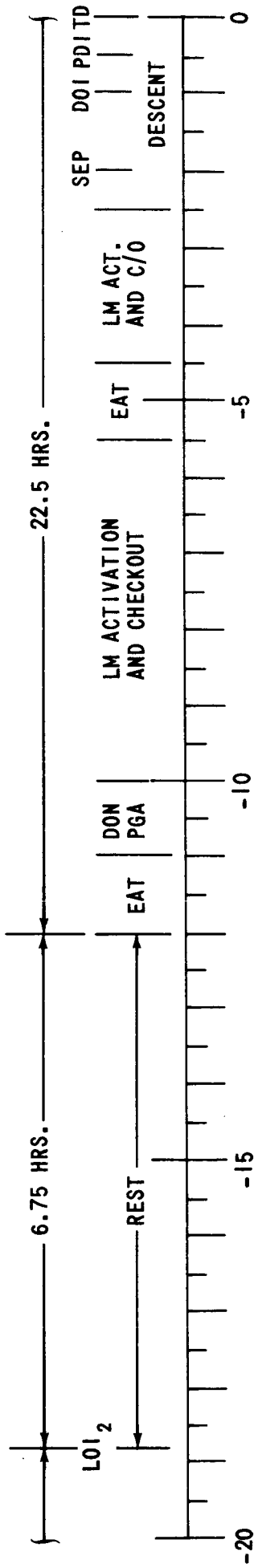
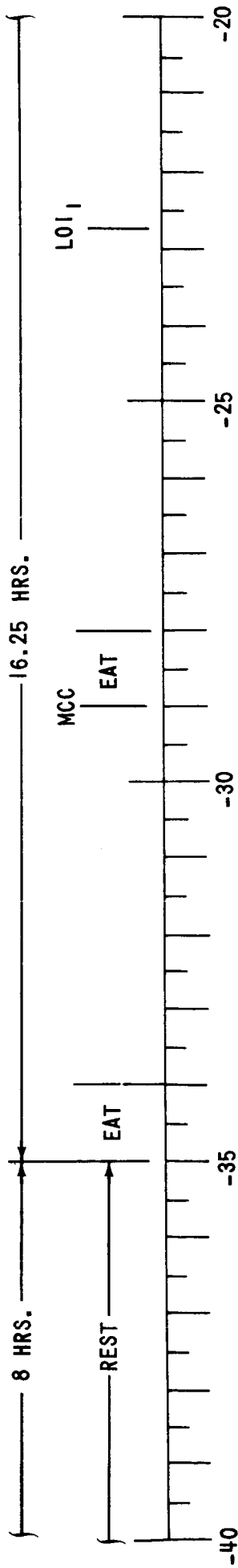
APPENDIX



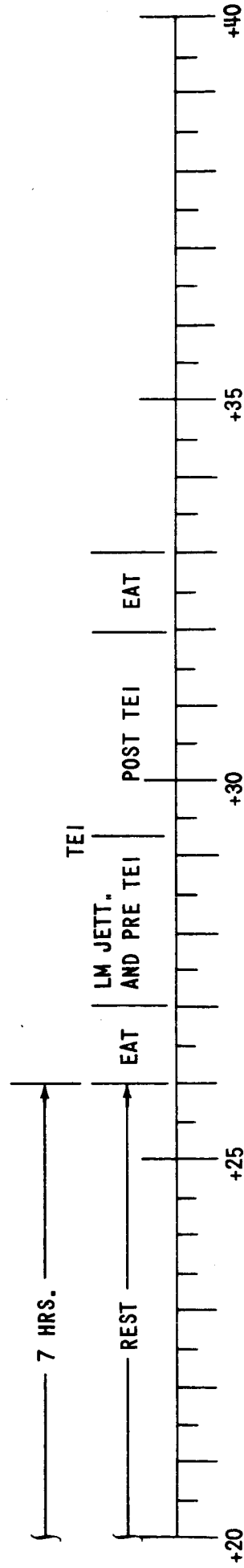
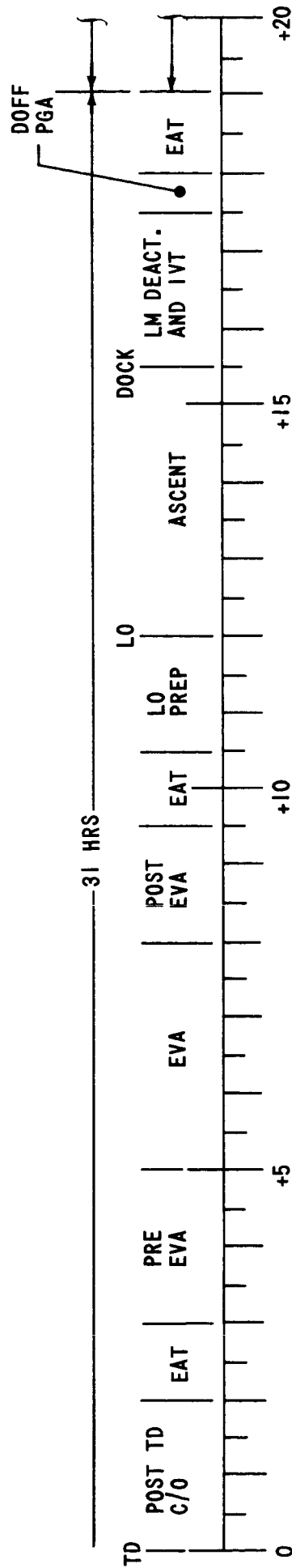
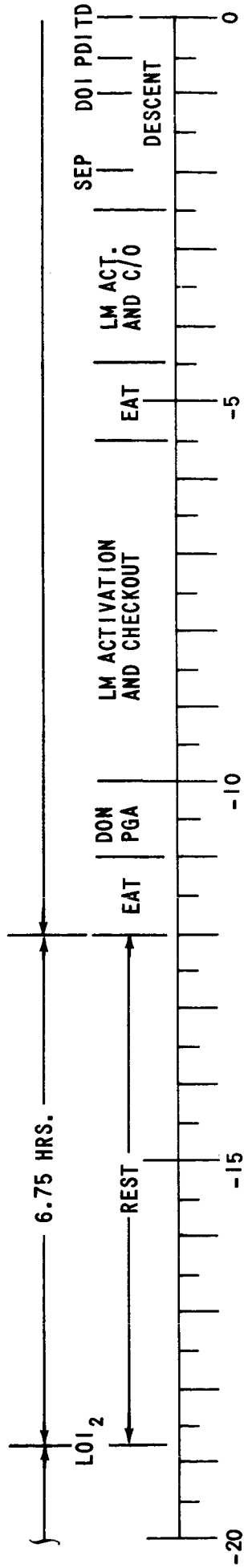
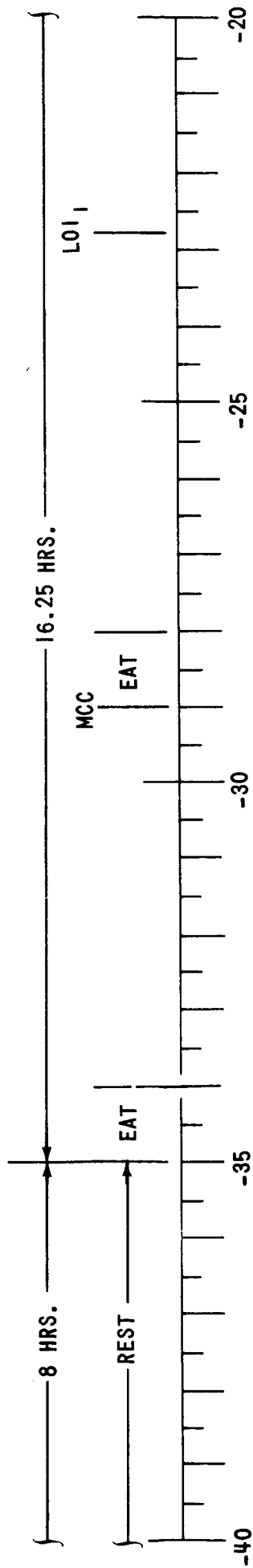


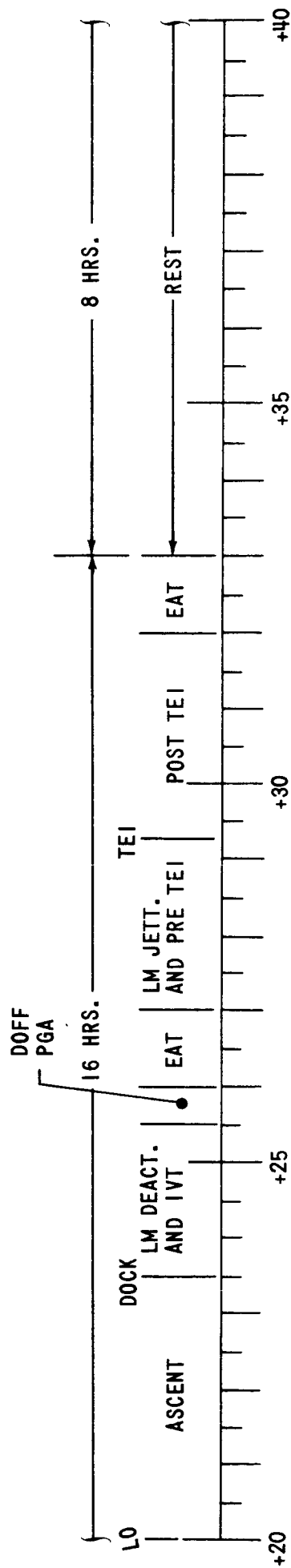
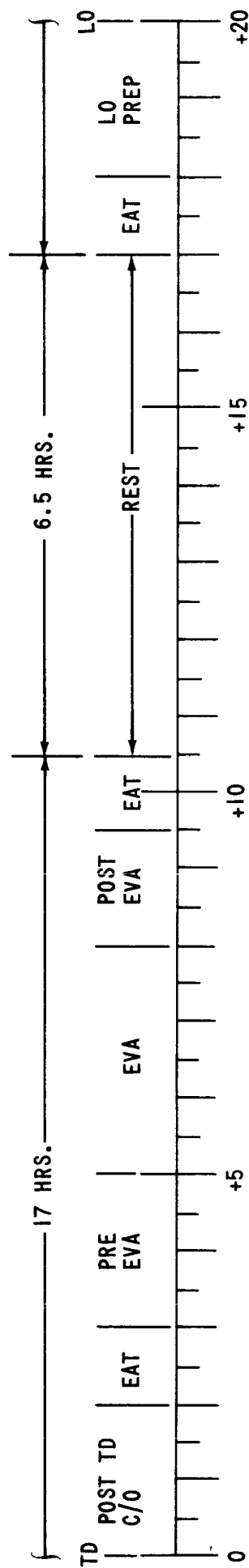
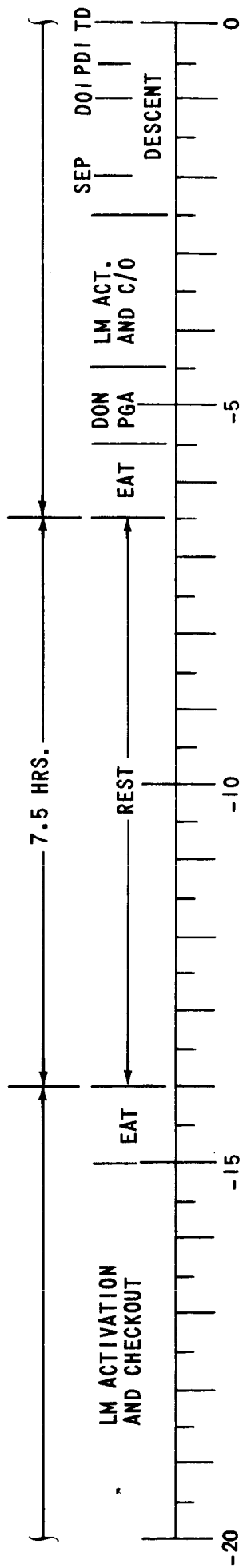
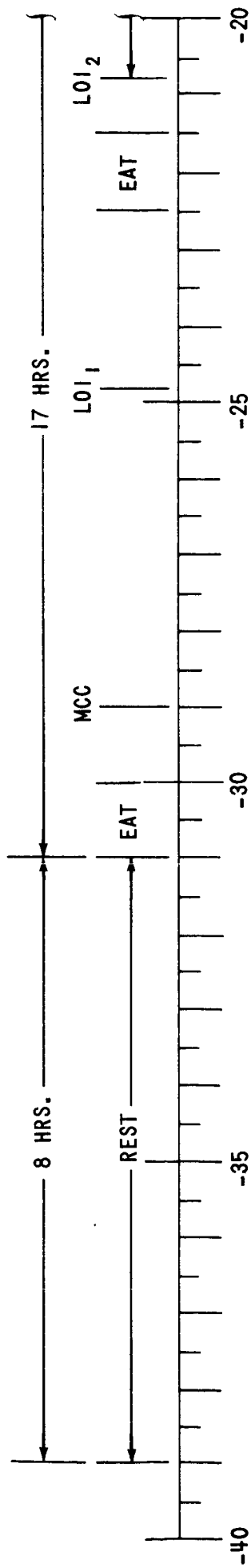


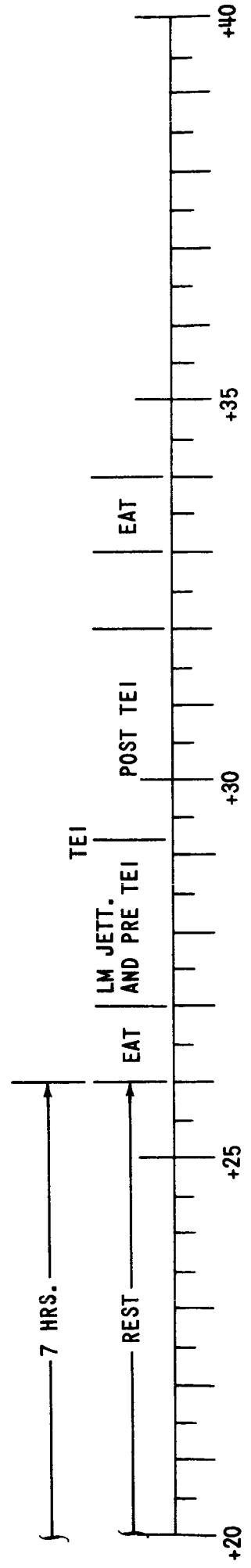
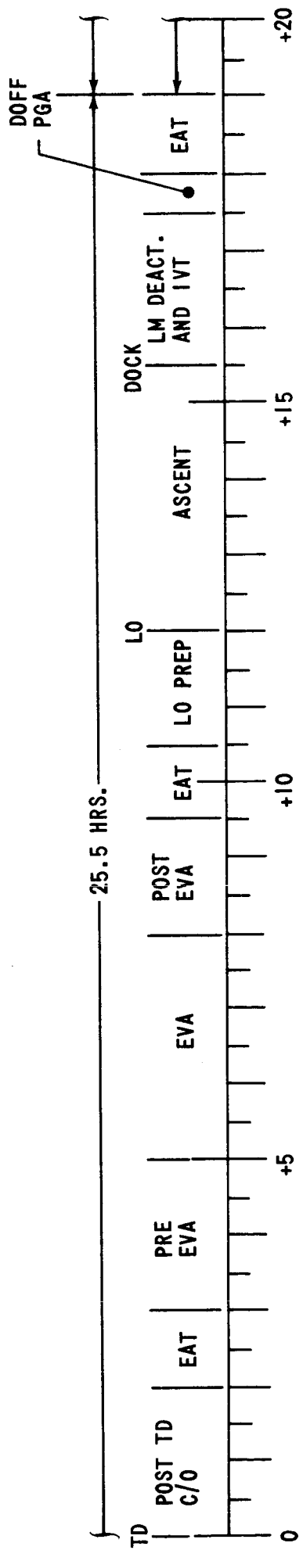
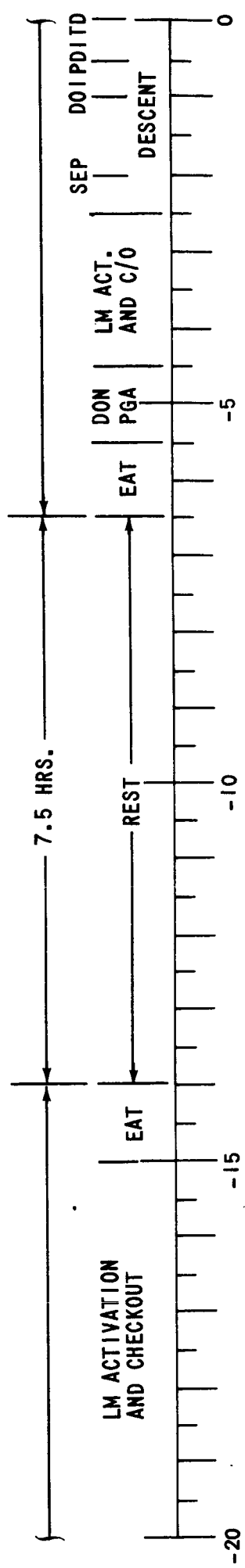
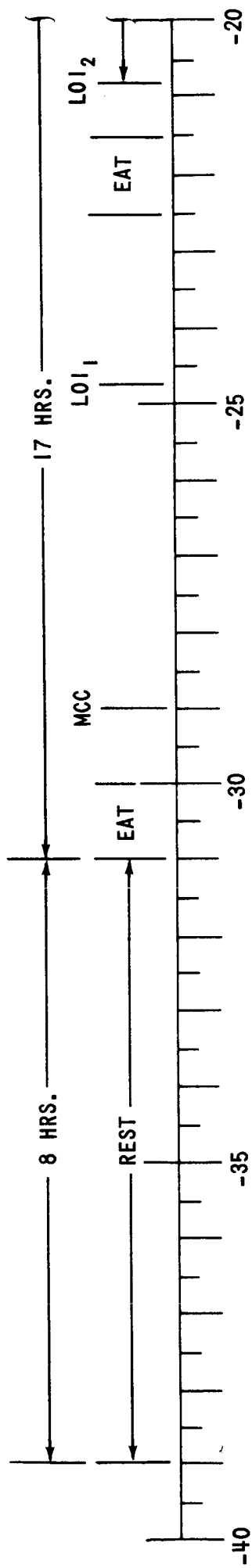
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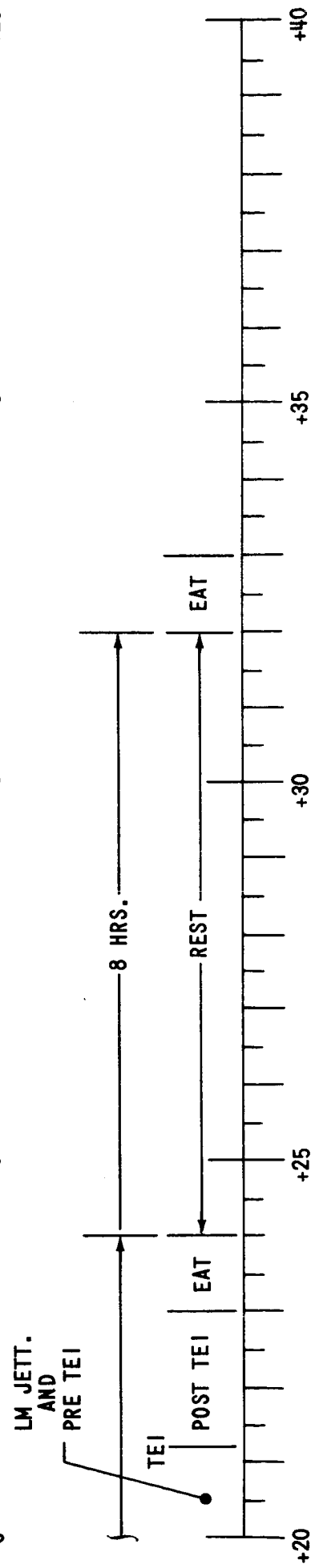
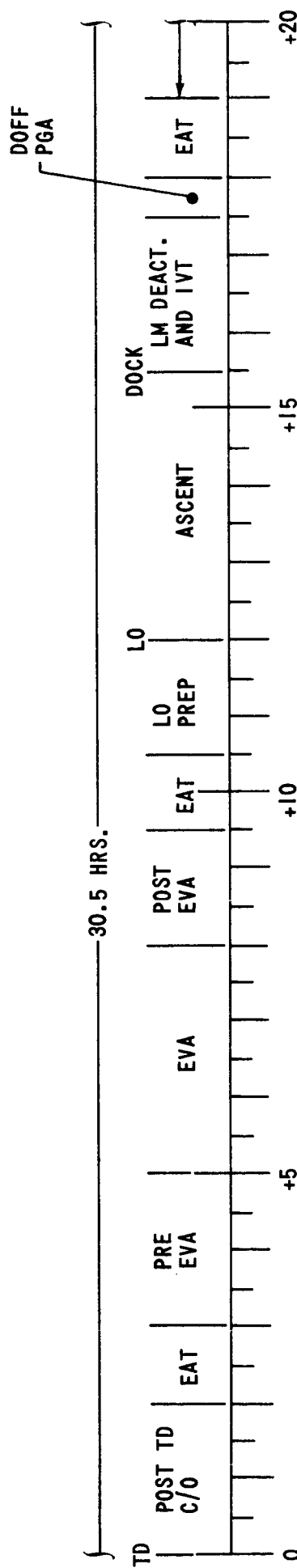
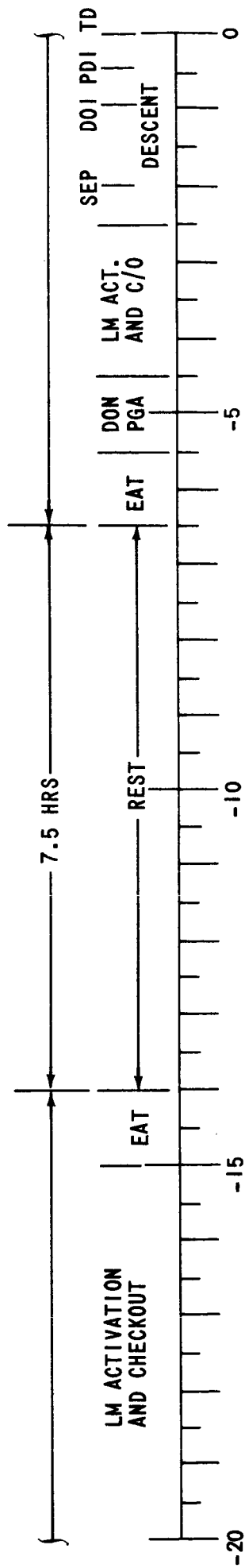
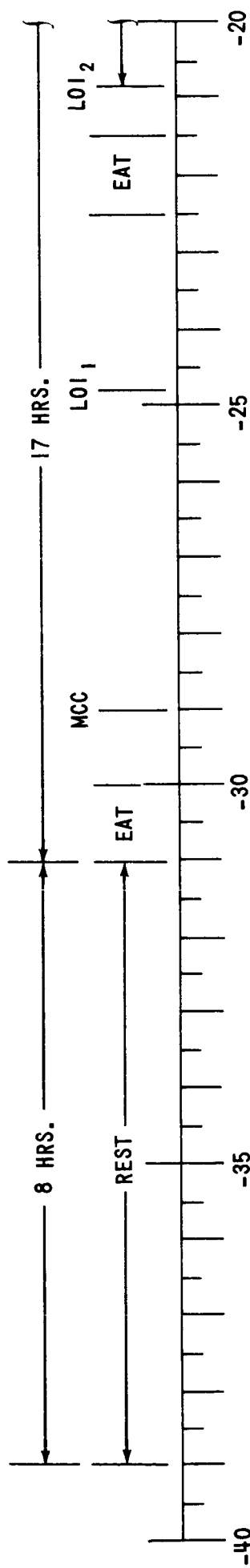


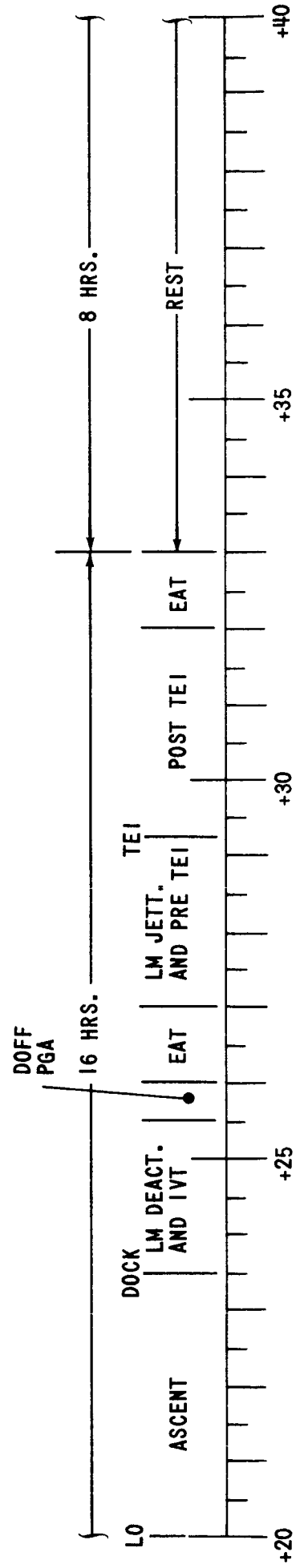
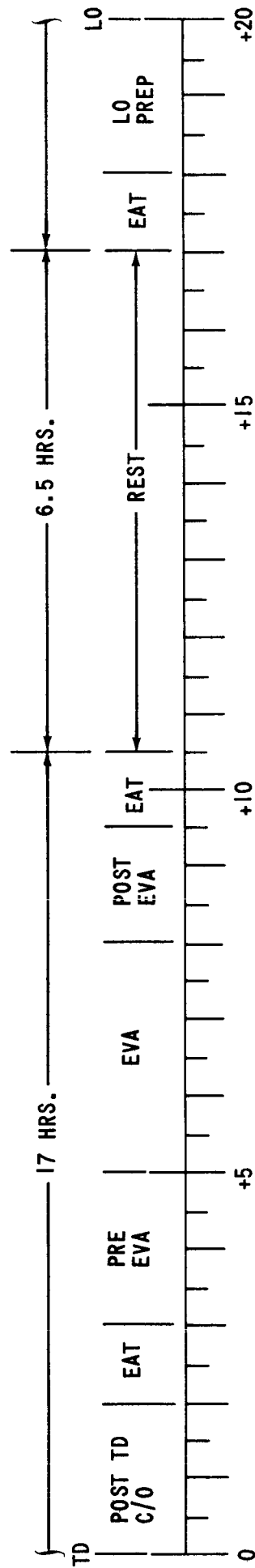
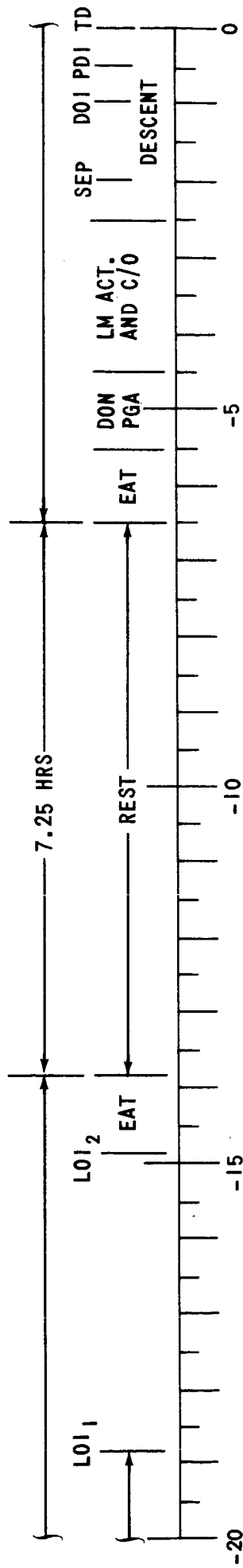
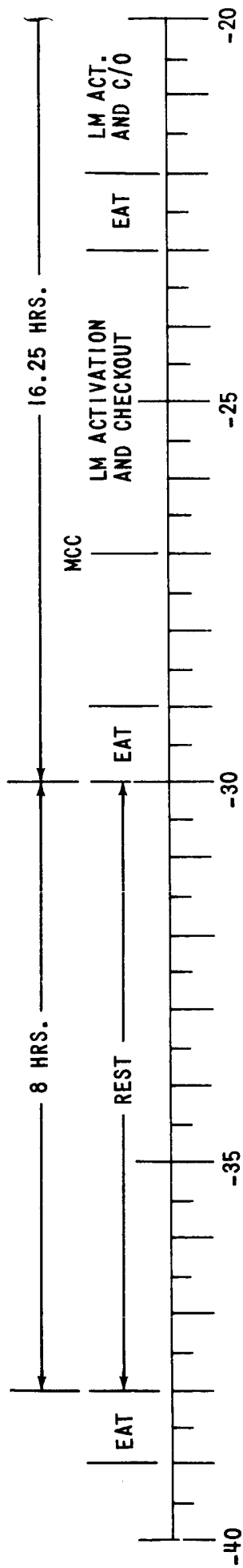
REAL TIME ALTERNATE A1b

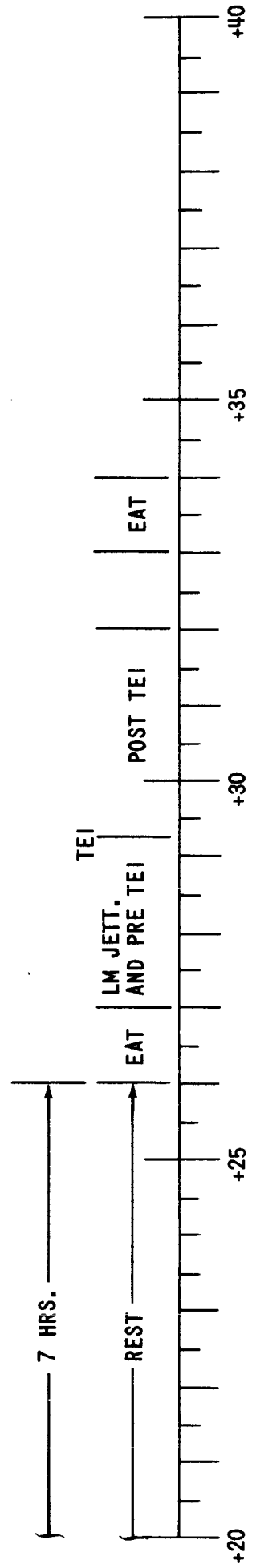
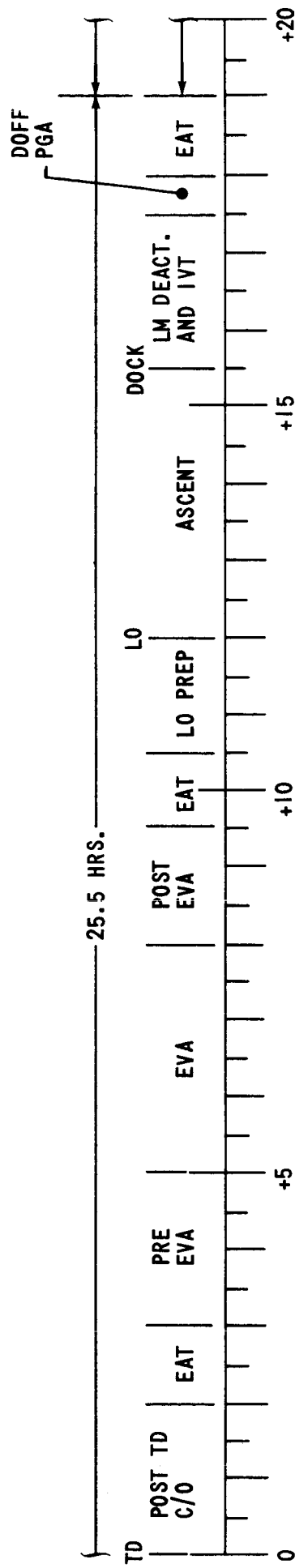
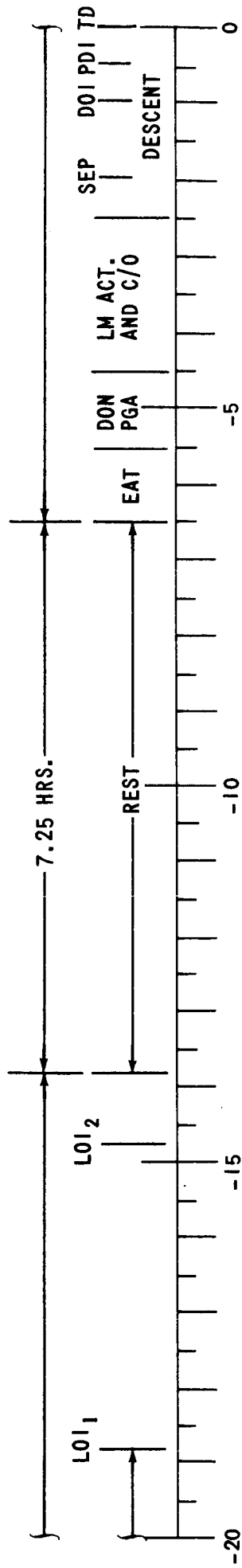
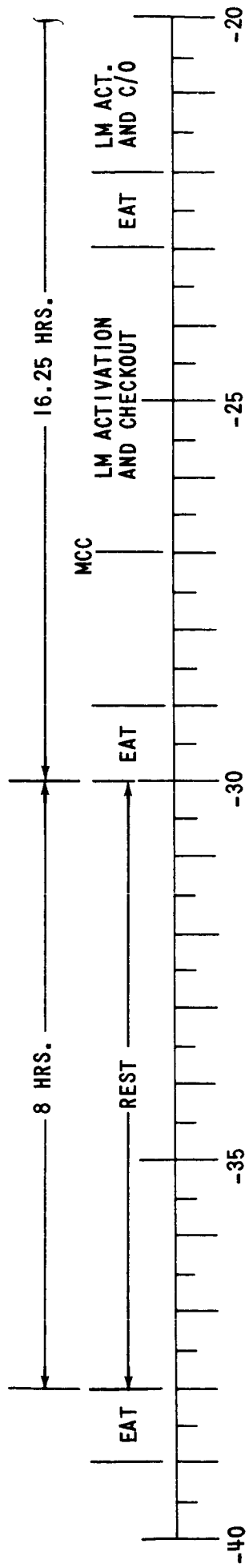


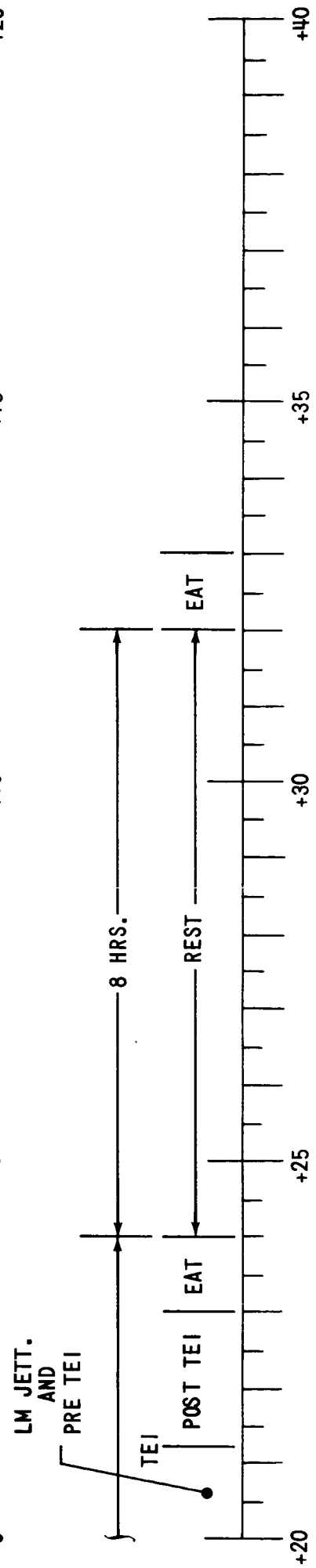
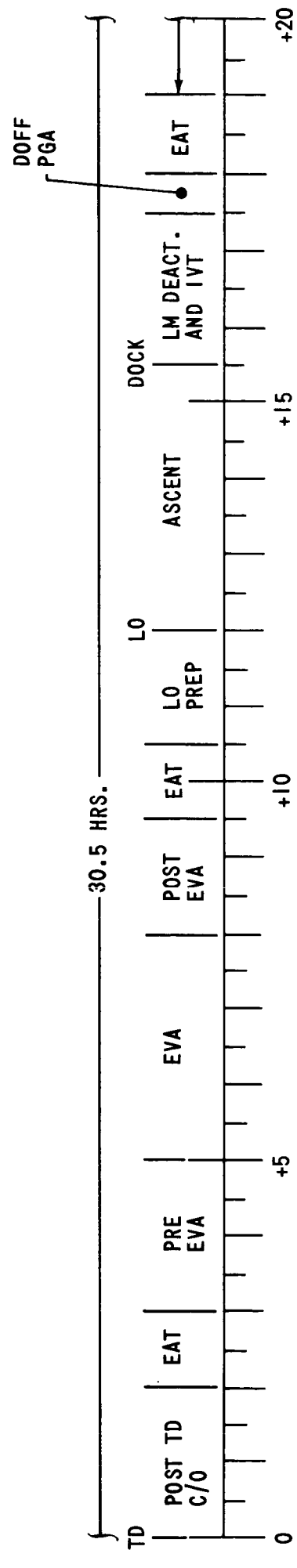
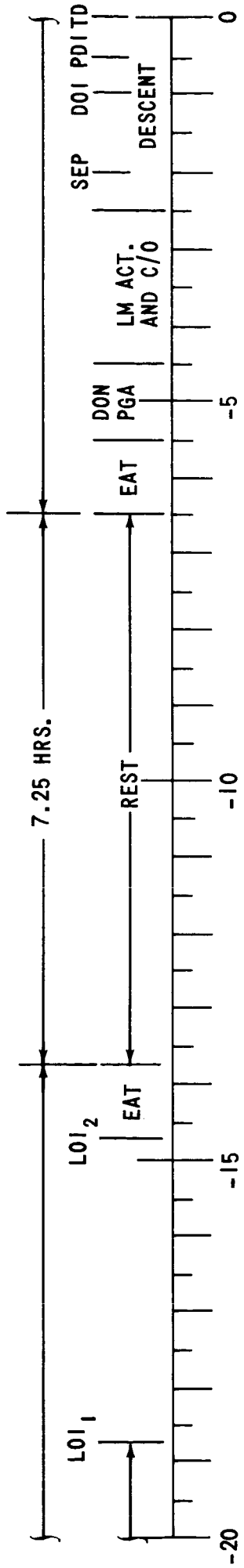
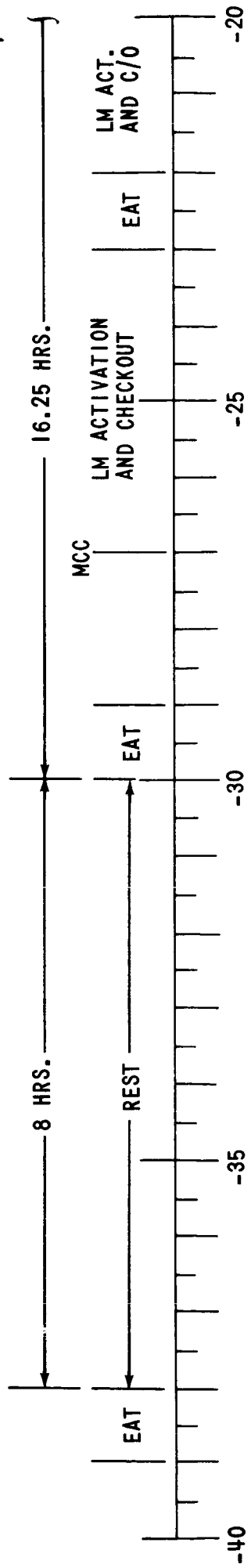


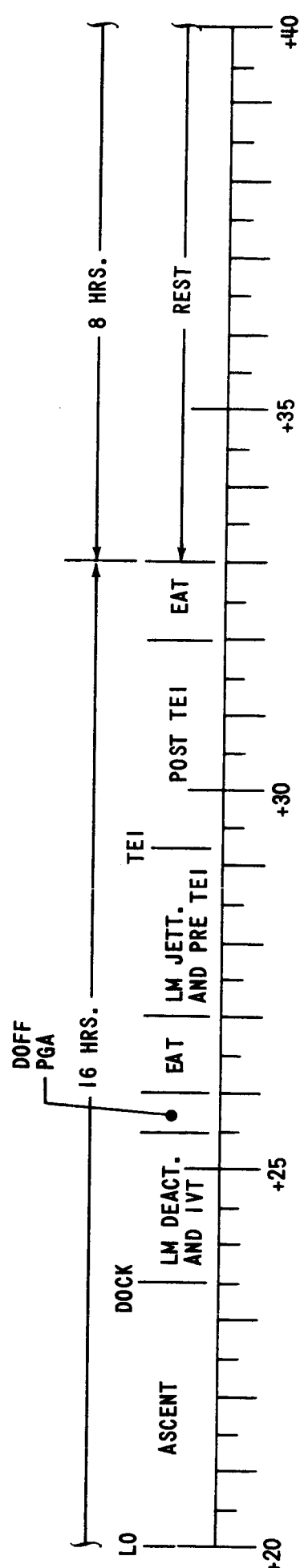
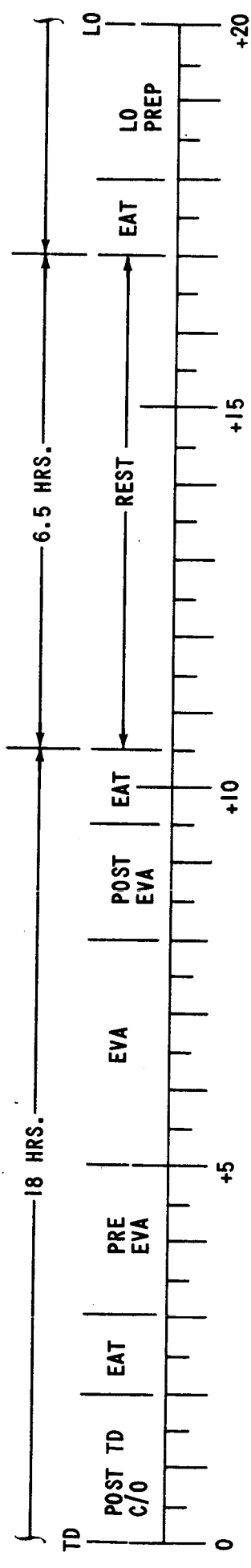
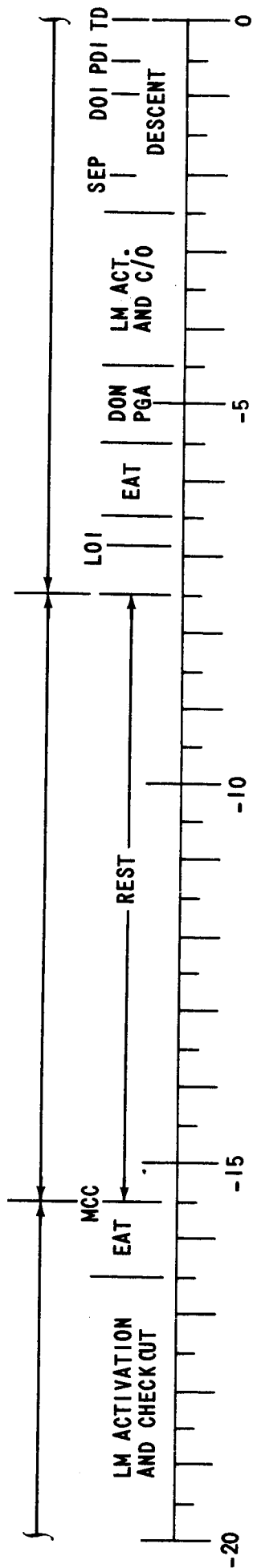
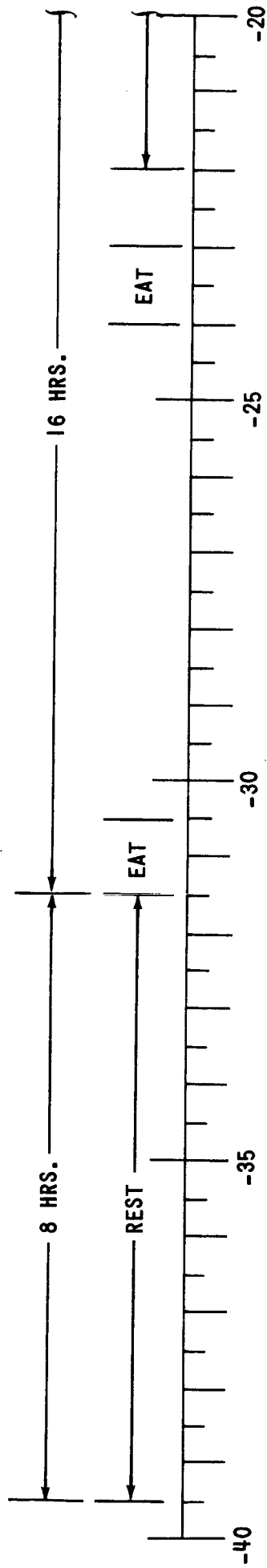


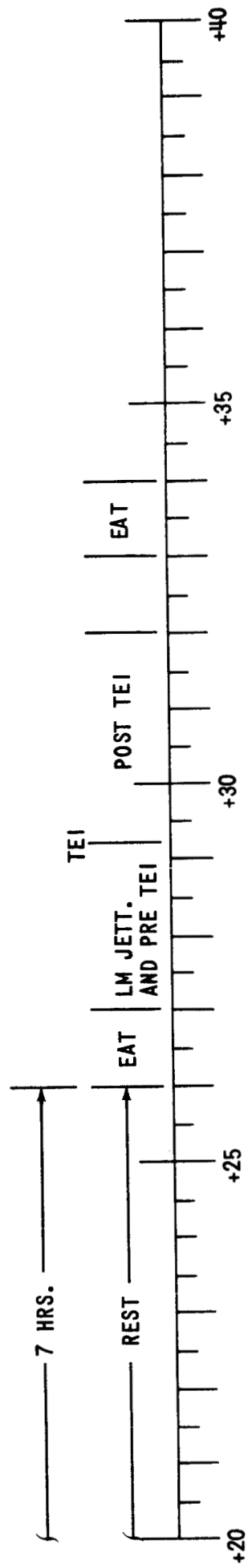
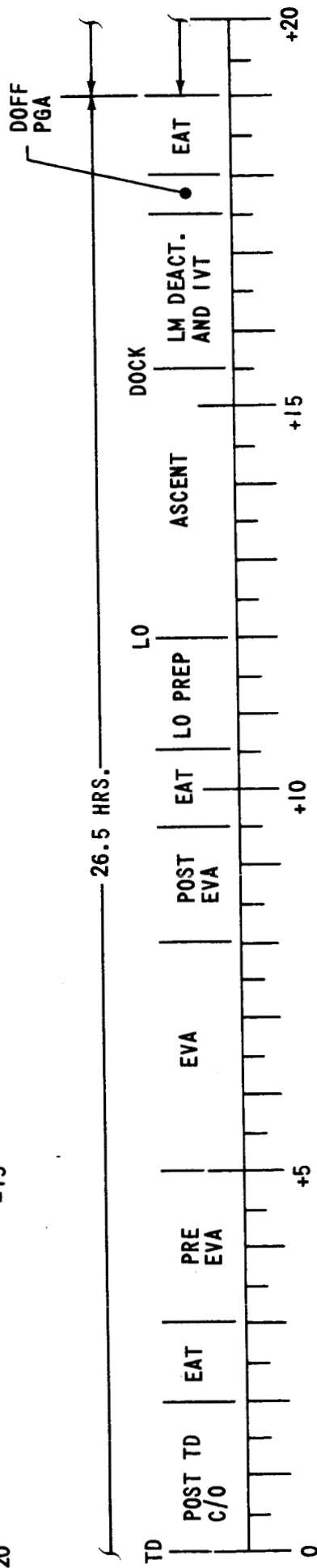
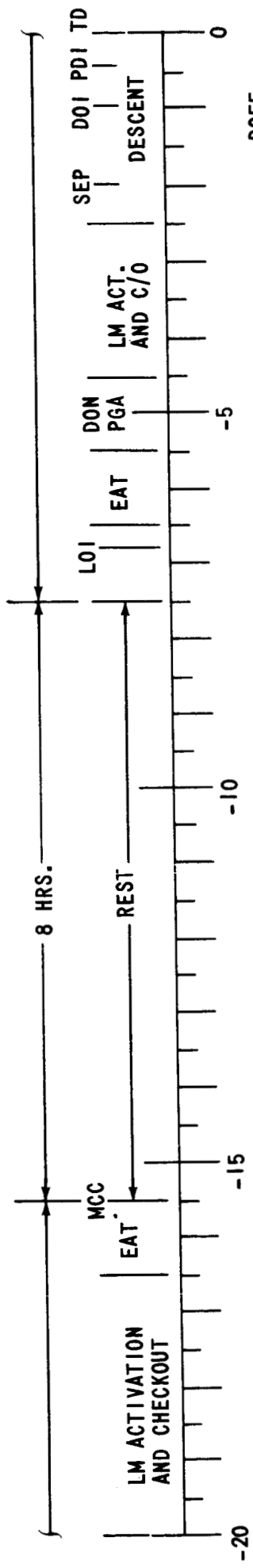
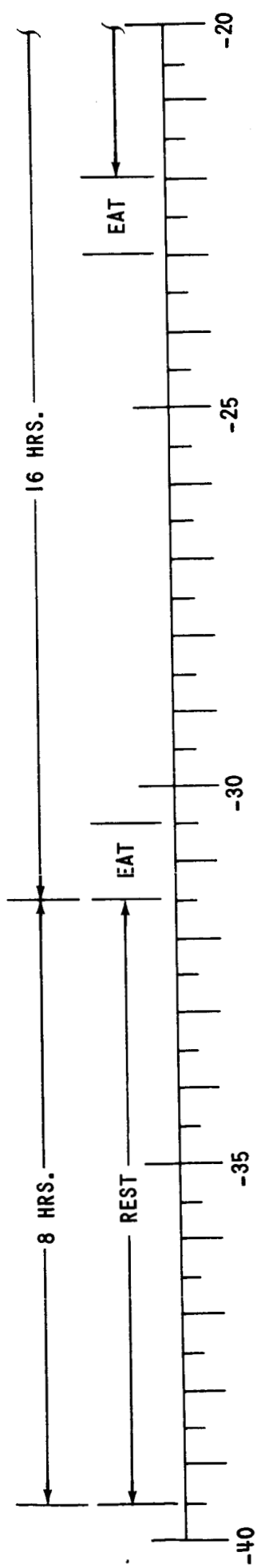












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